Speech Communication across the lifespan

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Introduction

The task that an infant faces when acquiring speech and language can be likened to deciphering a fiendishly complex code. What makes speech so complex is the fact that there is a lack of constancy between the acoustic signal and the abstract referent that it represents. Indeed, the acoustic patterns that cue phonetic distinctions vary from talker to talker. This between-talker variability is partly linked to the physical make-up of the talker, which to a great extent determine the acoustic characteristics of the speech that is produced. Talkers may also vary from each other in terms of their regional accent (Jacewicz and Fox, 2016), or the social and gender markers in their speech. Further variability in this complex code arises because a given talker will not produce acoustic patterns in an identical fashion even when uttering the same word on different occasions: much of this within-talker variability occur as a function of how fast we speak and in what speaking style, the physical and mental health of the talker, and other such factors.

The fact that infants are able to show a basic understanding of speech and begin to utter their first words within the space of relatively few months after birth is a source of wonder, and speech acquisition has been the focus of extensive research in the speech and language sciences. In the traditional view of acquisition, development in childhood is seen as a trajectory towards an 'adult norm.' Indeed, many studies are concerned with establishing when this adult norm is achieved for different aspects of speech production or perception. Given the population typically tested in experimental studies, this adult norm has been based on the testing of undergraduate university students within an 18 to 25 year age bracket. However, a picture is increasingly emerging that there are ongoing changes in speech production throughout the lifespan, from childhood into old age. The notion of an 'adult norm' as target for speech development is therefore becoming more blurred.

In this paper, I will briefly review factors affecting these lifespan changes following the very initial stages of speech acquisition in preschool children, and how they affect the production of speech. I arbitrarily define as 'infant' an individual aged from birth to 3 years, as 'child,' aged between 3 and 12 years, 'adolescent' between 13 and 18 years, 'young adult' between 19 and 35 years, 'middle-aged' between 36 and 64 years, and 'older adult' as aged 65 upwards. I will also argue that investigating speech produced in communicative settings, for example involving speech produced in order to impart a message to another talker, gives a more ecologically-valid picture of speech production changes across the lifespan than can be obtained from more traditional 'laboratory speech'.

Early development of speech production

In the last few decades, there have been tremendous advances in our understanding of how speech is acquired, with a strong focus on development in infancy up to the age of 5 years. It is beyond the scope of this article to provide a summary of this vast research literature so only a few key findings are mentioned here. Recent work has particularly highlighted the influence of the language environment experienced by an infant on their development of speech. To investigate the impact of language input on word learning, a researcher from the MIT Media lab famously recorded about 70% of his son's speech exposure and interaction with his caregivers between birth and the age of three years via an array of microphones and video cameras installed in his house, resulting in over 250,000 hours of audio and video (Roy, 2009; Vosoughi and Roy, 2012). Even a very partial analysis of this unique corpus allowed Roy's research team to examine 'word births,' that is early utterances of lexical items related to the exposure that his son had had to these words and the physical context in which they were heard. This work also showed how attuned caregivers were to the stage of development of his infant, adjusting the length of their utterances and the diversity of their lexical items accordingly.

Even though this unique study is unlikely to be replicated, the move towards 'big data' has been facilitated by the development of devices such as LENA Pro (e.g., Oller et al., 2010). This device can record up to a full day of an infant's sound environment and provides an automatic classification of the speech and environmental sounds that the infant is exposed to as well as of the infant's own vocalizations. Studies based on such data can show links between the amount of conversational turns and later linguistic outcomes for example (e.g., Ambrose et al., 2014). The importance of social interaction and joint attention for speech development has also been shown in more controlled laboratory studies. For example, in a study of interactions between 8 month olds and their mothers, infant vocalizations were significantly higher and more mature when the mother's social response (smiling, moving closer to the infant) was synchronized to the infant's vocalization than when a similar amount of feedback was present but manipulated to be desynchronized from the child's vocalization (Goldstein et al., 2003).

Later stages of speech development in childhood

Even though children are efficient communicators by the age of five, their development of speech production is still far from complete. The differences that can still be measured relative to an 'adult norm' may be subtle and only identifiable using analytic tests but they are still likely to have an impact on every day communication. The fact that there are ongoing changes in speech production throughout childhood is perhaps not surprising when one considers the very significant physical and cognitive changes that occur in this period and especially around puberty. The dimensions of the vocal tract increase with body size, as shown by a study involving MRI scans of individuals aged 2 to 25 years (Fitch and Giedd, 1999), with differentiation according to talker sex appearing around puberty and marked by a particularly marked growth in pharyngeal length in males. There are also physical changes to the larynx which occur for individuals of both sexes but are especially marked in males during puberty, resulting in a marked increase in the size and thickness of vocal folds (e.g., Hollien et al., 1994).

The acoustic consequences of these physical developments are many. In terms of the voice source, physical changes in the larynx lead to a decrease in the frequency of vocal fold vibration, which determines perceived pitch. This decrease occurs in for both sexes but is particularly marked in males, thus leading to a greater differentiation according to talker sex at puberty (e.g. Hollien et al., 1994). Due to changes in vocal tract size, the acoustic patterns characterizing vowels (e.g., Lee, Potamianos & Narayan, 1999; Perry et al., 2001) and consonants (e.g., Mc Gowan and Nittrouer, 1988; Romeo et al., 2013) that result from resonances in the vocal tract also decrease throughout childhood as vocal tract size increases.

Some changes that occur in children's speech are not due to physical changes but to the increasing use of gender or social identity markers. An article on the acoustics of regional accents, one such marker, recently appeared in *Acoustic Today* (Jacewicz and Fox, 2016). As an example of gender marker, the sound 's' as in 'Sue' is produced with a higher frequency of frication for girls than boys to a degree beyond what would be expected from differences in physical characteristics alone (Flipsen et al., 1999). Sociophonetic studies have shown that variants signalling gender or social identity are already documented by the age of 3 years and that there is evidence also that mothers may use different phonetic variants when speaking to girls and boys (Foulkes et al., 2005). In a recent study (Munson et al., 2015), boys in the 5-13 year age range diagnosed as experiencing gender identity disorder, that is, who were distressed or uncomfortable with their biological status as male, produced vowels and consonant sounds such as 's' that differed acoustically and were perceived as less male-like than for boys with typical gender identity. This further suggests that phonetic markers of gender identity can be established early, as well as appear later in adulthood as one's gender and social identity is established further.

Younger adolescents differ from young adults, not only in terms of the frequency ranges of the acoustic patterns of their speech, but also because they are more internally-variable in their speech production (e.g. Koenig et al., 2008). This greater variability in production can be measured directly from articulatory movements (Walsh and Smith, 2002). The acoustic consequences of this immature motor control can be seen in the form of larger variance in acoustic characteristics of sounds in the speech of children and young adolescents when multiple repetitions of the same items are measured (e.g., Lee et al., 1999; Munson, 2004).

Another aspect that is still undergoing development is the rate at which children and adolescents articulate their speech, typically measured as the number of syllables produced per second. The development of conversational articulation rate, as measured from tasks such as story retelling or monologues on familiar topics, is of particular interest because it reflects the joint influence of two components: speech motor control and linguistic planning (Flipsen, 2002; Nip and Green, 2013). Developmental studies of conversational articulation rate typically show evidence of age effects throughout the first and into the second decade of life (e.g. Sturm and Steery, 2007; Flipsen, 2002).

It is notable that even studies of later speech development seem to exclude adolescents older than 14-15 years; this is primarily because some early studies of speech perception and production in this age range suggested that performance stabilized from that age onwards, but there may also be a more pragmatic reason as it can be difficult to entice older adolescents to participate in laboratory experiments. Evidence is accumulating though that further refinement in speech production abilities must occur in these years, as 14-15 year olds still differ significantly from young adults in studies of the coordination of motor articulation (e.g., Smith and Zelaznik, 2004) and acoustic characteristics (e.g., Hazan et al., 2016) of speech production.

In addition to physical changes in their vocal apparatus, adolescents are also undergoing significant cognitive changes as a result of changes to brain structure and this may impact on their speech communication. For example, relative to young adults, adolescents have greater difficulty with perspective-taking, which is an essential requirement for effective communication (Blakemore and Choudhury, 2006). It is also the case that school-age adolescents have yet to experience the great changes in language experience and exposure that undergraduate students, who constitute the typical 'young adult' population in speech science studies, usually experience when leaving home to go to university. This great increase in language experience may well contribute to the differences seen between these two age groups despite their small age gap; this issue requires further investigation.

Further changes in speech production in middle age

As suggested above, 'adult norms' in speech science studies usually equate to the performance of undergraduate students in their lower to mid-20s for practical reasons of participant recruitment rather than more principled selection criteria. Middle-aged adults are probably the least studied population in speech research. They are the hardest population to recruit due to limited availability in working hours, and there is also an expectation that they might not be a particularly interesting group to investigate as speech perception and production abilities are expected to be stable. However, the few studies that have spanned a large age range in adulthood suggest that this may not be the case. For example, Jacewicz et al. (2010) showed that articulation rate measured from spontaneous speech monologues increased from childhood into adulthood and did not 'peak' until adults were in their mid-40s.

There are many factors that could contribute to ongoing changes in speech production abilities throughout mid adulthood. First, our exposure to language in all its variants is incremental throughout the lifespan and the learning of a new language in adulthood, for example, can affect the production of native language (Chang, 2012). Sociophonetic factors linked to regional or social mobility are also influential as individuals can change their accent significantly in adulthood as a result of moving to a new region or moving to a new work environment, although the extent of this change will most likely depend on the degree to which they wish to retain their identity (Evans and Iverson, 2007).

Speech production in mid-adulthood can also be affected by changes in physical or mental health. Major traumas such as stroke or cancers affecting the larynx or tongue can have a significant impact on speech. Less drastic physical changes such as those brought about by heavy smoking or excessive alcohol intake can also affect voice production and lead to perceptible changes in voice quality. Many occupations that involve individuals excessively using their voice can lead to voice changes; for example, teachers show a greater incidence of voice disorders than do non-teachers (Roy et al., 2004). Many women in their fifties may experience significant changes to their voice due to hormonal changes linked to the menopause which cause physiological and functional changes to the vocal folds (see review in D'haeseleer et al., 2009). This can result in a decrease in fundamental frequency linked to increased vocal fold mass although it is difficult to separate the effects of the menopause from those of vocal aging. Changes in pitch characteristics and speaking rate can also be seen in adults as a result of depression or other mental health issues (for review, see Cummins et al., 2015).

Speech production in later adulthood

When considering how speech production changes in later adulthood (e.g. 65 years onwards), one finds a number of factors that are surprisingly similar to those that affect adolescents. In both age groups, changes in vocal tract size occur, with documented increases in vocal tract length in older adults, resulting in increased vocal tract volume (Xue and Hao, 2003). Both age groups also experience changes affecting the larynx although these are less drastic in older adults, where the physiological changes to the larynx include a thinning of vocal folds and hardening of laryngeal cartilages. Also, motor control appears to be reduced in both groups compared to young adults: adolescents and older adults show greater within-speaker variation in articulatory movement and placement. Finally, there are cognitive changes in both groups that may affect the willingness to make additional efforts to be understood and the empathy experienced towards a conversational partner. This could affect the effort they are prepared to make to be understood by an interlocutor who is having problems communicating. A useful review of various influencing factors can be found in Hooper and Cralidis, 2009).

These various factors can lead to changes in speech production in older adults although the degree to which these affect the ability to communicate effectively and fluently is still a matter of debate; there is great individual variability in speech production performance given the complex interrelation of many external influencing factors such as physical and mental health, cognitive abilities, and hearing. Typically, changes have been shown in pitch characteristics, with the fundamental frequency of the voice reducing with age in women but increasing or remaining stable in men. Vocal fold vibration also tends to be less stable in older talkers resulting in decreased stability both in terms of frequency and amplitude of the sound source (for review, see Baken, 2005). In terms of speech articulation, older talkers may show reduced accuracy relative to young adults when producing complex novel words (Sadagopan and Smith, 2013) although older adults showing high accuracy do not show decrements in motor coordination, and age-related differences were only found in that study for long words with a complex structure. Articulation rate has also been shown to be reduced in older adults as compared to young adults both for read speech and conversational speech (Jacewicz et al., 2010).

In addition to these changes to speech production, older talkers also show other changes which can affect their ability to communicate effectively. It is well documented that a high proportion of older adults experience a degree of age-related hearing loss or presbyacusis which has a number of consequences (see review in Gordon-Salant, 2014). Hearing thresholds are raised, especially for high-frequency sounds, and dynamic range reduced. Presbyacusis is also linked to a broadening of auditory filters within the cochlea which has the serious consequence of making it especially difficult for individuals to perceive speech in noisy environments due to increased masking.

This combination of potentially weaker speech production and difficulties in perceiving speech can lead to a 'perfect storm' at least for individuals in later old age conversing with each other. These older adults may find it difficult understanding each other and may not be able to counteract these problems as effectively as younger adults by making adaptations to their speech production, such as using a 'clear speaking style.' To compound these difficulties, if conversing in a day care environment, for example, interference from a television or radio in the background or other conversations may further affect the ability to communicate effectively.

Examining speech production in spontaneous speech across the lifespan

Most studies examining speech production characteristics at points along the lifespan have based their investigations on speech produced in laboratory settings, with talkers reading materials such as word or sentences or doing tasks to elicit spontaneous speech monologues such as describing a picture or recounting a simple story. Although such an approach enables researchers to record speech which is well-controlled and comparable across talkers, it lacks a key dimension in speech production which is that of communicative intent. The speech produced in this way would not reflect how speech production would be affected by the difficulty in interacting described above for older adults, for example. Indeed, in everyday life, speech is typically produced while communicating with another speaker, and our key aim is to ensure that the message that we are imparting to our interlocutor is understood so that communication can continue efficiently. We typically do this by adapting our speech dynamically throughout our interactions, producing more clearly articulated or 'hyper-speech' when communicating in adverse conditions but resulting to less clearly articulated 'hypo-speech', requiring less effort to produce, when the message we are imparting is highly predictable (Lindblom, 1990). Most communication occurs at some point along this 'hyper' to 'hypo' continuum, and the degree of effort used to produce speech changes dynamically according to the ongoing level of understanding of our interlocutor. We assess this level of understanding via the appropriateness of their responses, the frequency of requests for clarification, pauses, and hesitations. Recently, there has been a move towards investigating how talkers of different age groups adapt their speech in different communicative conditions using problem-solving tasks involving dialogues between two individuals (for a review, see Cooke et al., 2014). These dialogues may still be far from natural communication, as they are recorded in the laboratory and may involve talkers carrying out a specific problem-solving task in order to maintain some control over the content of the interaction, but they do provide information about speaker adaptations inherent to speech communication that cannot reliably be gleaned from read speech or spontaneous speech monologues.

One of the challenges of studies carried out with very different age ranges is to find a task which is useable across a broad age range and which imposes a similar degree of cognitive load, as far as this can be ascertained. Some studies have used a 'spot the difference' picture task, 'diapix' (van Engen et al., 2010; Baker and Hazan, 2011) that involves pairs of talkers conversing to find differences between their pictures without sight of their partner's picture. Others have used other interactive tasks such as Sudoku, the matching of complex shapes (tangrams), or tasks that involve one talker describing a trajectory on a map to another (Map Task). To investigate how individuals of different ages adapt their speech when communicating in adverse listening conditions, controlled disruptions to communication between two talkers, such as adding noise or spectrally-distorting the speech of one or both talkers during their interactions can be introduced (for a review of this type of work, see Cooke et al., 2014).

In a series of related studies with children aged 9 to 14 years, young adults and older adults aged 65 to 85 years, using a diapix task, trends for articulation rate (syllables produced per second) in conversational speech showed an inverted U shape with children up to the age of 11 speaking at a slower speech rate than young adults (Hazan et al., 2016) but older adults in the 65-85 year age range also speaking at a lower articulation rate than young adults (Tuomainen and Hazan, 2016) (**Figure 1**). Normalized pitch range showed a similar picture: 13-14 year olds and adults used a narrower pitch range in their conversational speech than both 9-12 year olds and 65-85 year olds. Change in mean fundamental frequency followed expected trends in terms of talker sex and age [see demo: http://valeriehazan.com/wp/index.php/speech-production-across-lifespan/] (**Figure 2**).

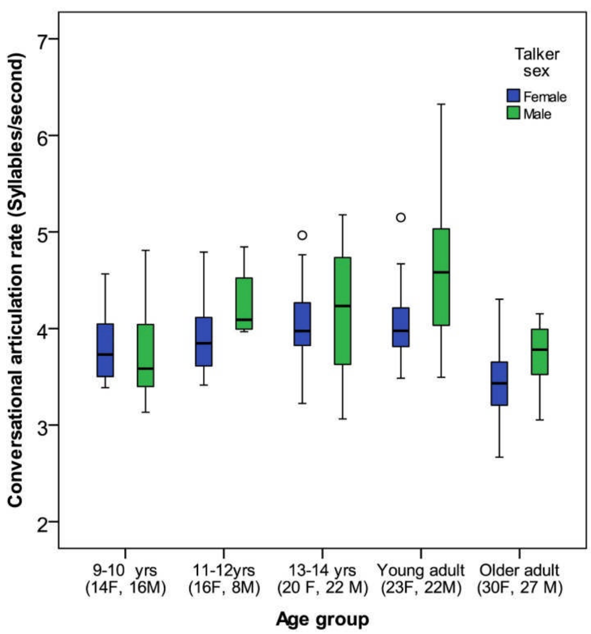

Figure 1: Conversational articulation rate based on data collected during 'spot the difference' tasks (diapix) carried out between pairs of talkers. These data have been accumulated across studies carried out with children (reported in Hazan et al., 2016) and with young and older adults (reported in Tuomainen and Hazan, 2016). The circle symbols in the figure denote outliers.

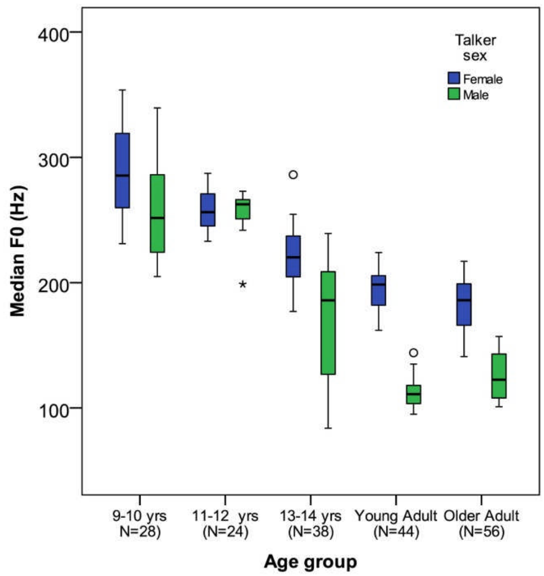

Figure 2: Box plot showing changes in median fundamental frequency across the lifespan, based on data collected during 'spot the difference' tasks (diapix) carried out between pairs of talkers. These data have been accumulated across studies carried out with children (reported in Hazan et al., 2016) and with young and older adults (reported in Hazan and Tuomainen, 2016). The circles and star symbols denote outliers.

In those same diapix studies, when communication was made more difficult between conversational partners the adaptations made by 9-14 year olds, and especially the younger group of 9-10 year olds, were quite consistent with a general increase in vocal effort (shouting), while young adults varied more in the strategies that they used to make their speech clearer (Hazan et al., 2016). This suggests that 9-14 year olds were still developing a full range of these strategies that are essential for efficient communication. Ongoing work with older adults appears to be showing a similar trend with changes also consistent with an increase in vocal effort and less evidence of reducing their articulation rate, although this is a strategy typically used by younger adults (Tuomainen and Hazan, 2016).

Moving towards lifespan studies

The changes in speech production across the lifespan documented above suggest that we should view speech communication as a highly-dynamic process. This process is dynamic not only because of the ongoing adaptations that are made in communication to adapt to different environments and differing needs of our conversational partners, but also because our speech undergoes ongoing adaptation throughout our life.

Currently, our understanding of these lifespan changes is limited by the lack of studies that span a large age range. Longitudinal studies spanning several decades would be fascinating but impractical, although a small number do exist, for 'exceptional' individuals such as Queen Elizabeth II and British radio broadcaster Alistair Cooke (**see Figure 3**), for whom there are recordings over a fifty year period (Reubold et al., 2010), or for groups of individuals who have been recorded at regular interviews throughout their lifetime as in the British 'Up' set of documentaries (Gahl et al., 2014). These longitudinal studies reflect changes that result not only from physical aging but also from sociophonetic factors described above, as documented for Alistair Cooke, for example, who changed his accent several times throughout his lifetime (Reubold and Harrington, 2015).

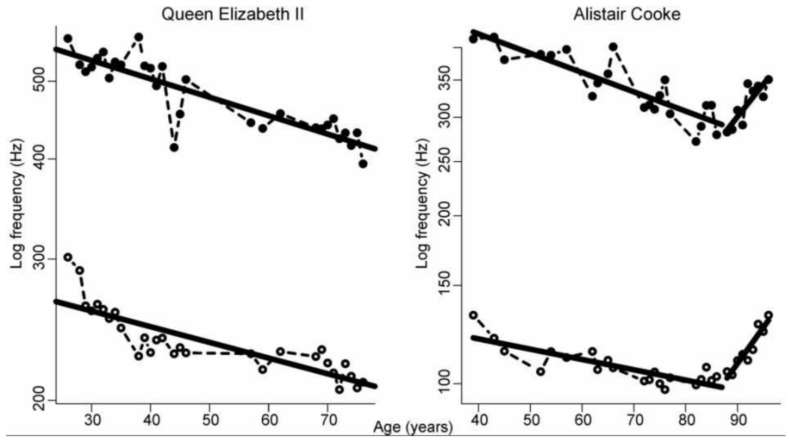

Figure 3: Data showing longitudinal changes in mean fundamental frequency (F0) and mean first formant frequency (F1) for two speakers recorded over a fifty year period: Queen Elizabeth II and the British broadcaster Alistair Cooke (reprinted from Speech Communication, vol 52, Reubold U., Harrington, J, Kleber, F., Vocal aging effects on F0 and the first formant: A longitudinal analysis in adult speakers, 638-651, 2010, with permission from Elsevier.).

Between-group lifespan studies, which should be more easily achievable, still involve a number of challenges. First few tasks and speech materials are useable for both children and adults, as factors such as lexical knowledge or working memory demands, need to be taken into account. Even when such tasks are found, one needs to consider whether they involve widely differing degrees of cognitive load for participants of different ages as this could impact on speech production. For example, if investigating changes in articulation rate across the lifespan, a task imposing a greater cognitive load for children and older adults than for younger adults could lead to slower articulation rate which is task-related. Participant selection criteria, which are already difficult to control within a specific target population become even more of a challenge across a broad age range, due to the wider range of external factors that could influence speech communication. The paucity of standardized cognitive and phonological assessments that are normed across a wide age range is a further limitation. Finally, it is still the case that a majority of researchers within the field of speech sciences that have an interest in the effect of age on speech communication specialize in either development studies or studies into ageing, with few having the practical experience of running studies with different age ranges, which each have specific demands and challenges.

Despite these many obstacles, moving from the currently fairly compartmentalized fields of speech research into development and aging to a lifespan approach, as already done by a few pioneers, could result in both a greater understanding of speech production and perception processes and of their interaction, and would also ultimately result in broader theoretical models of speech communication. Let’s embrace this challenge.

Author biography

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