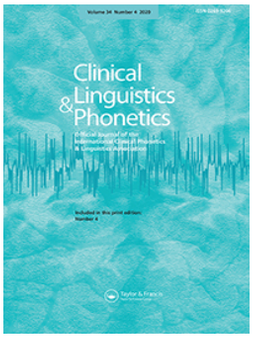

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The study of speech naturalness in communication disorders: A systematic review of the literature

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ABSTRACT

The concept of speech naturalness is used widely in clinic and research applications. Unfortunately, the lack of consistency in research methods means that comparing findings between studies is difficult at best. In order to better understand the state of research on speech naturalness in communication disorders and quantify these impressions, this study looks at publications from the last 18 years in a systematic manner. A literature search for the exact phrase "speech naturalness" of the PubMed/MEDLINE, EBSCO, and ASHAWire databases was conducted. Articles included in the review were studies of communication and communication disorders published between 1990 and the end of 2014, in English, and in a peer-reviewed journal. 63 articles were selected and coded using a coding sheet adapted from a prior systematic review on intelligibility and cleft palate. Speech naturalness is an object of study in many subfields of communication disorders. Several concerns were raised as a result of the review, including the reliability and validity of measures, inadequate definitions of terminology, lack of detail in method descriptions, and the need to address relationships between naturalness and other variables included in the studies. Future studies should more carefully report methods and operational definitions used and more studies examining the relationship between naturalness and other speech variables in a variety of communication disorders are greatly needed.

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Introduction

Naturalness is an overall, or global, measure of an individual's speech that is closely related to the individual's prosody and intelligibility. As one recent definition of naturalness states, "Speech is natural if it conforms to the listener's standard of rate, rhythm, intonation, and stress patterning, and if it conforms to the syntactic structure of the utterance being produced" (Yorkston, Beukelman, Strand, & Bell, 1999, p. 464). The concept of naturalness is used widely in clinic and research applications. For example, naturalness has been used in the investigation of perceptual differences between the speech of non-stutterers and post-treatment stutterers (Ingham & Onslow, 1985; Onslow & Ingham, 1987; Runyan, Hames, & Prosek, 1982; Sacco, Metz, & Schiavetti, 1992), the relationship between acoustic variables and natural speech (Metz, Schiavetti, & Sacco, 1990), and the

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effect of fingerspelling and perceived naturalness of speech during simultaneous communication (Schiavetti, Whitehead, Whitehead, & Metz, 1998), to name only a few.

Speech naturalness has been described in various ways for different speech disorders, sometimes with roughly equivalent terms such as acceptability. In the literature on stuttering, Martin, Haroldson, and Triden (1984, p. 53) describe unnatural speech as sounding "slow, paced, or monotonous and can be discriminated from [the speech of nonstutterers]." Manning (2001) describes such speech as uncomfortable to listen to and as having features that can distract the listener from fully attending to the content of the message. Conversely, Witzel (1995) defines acceptability as the listener's subjective impression of how pleasing the speech is. The latter definition is especially vague and could invite listeners to rate non-impaired speech as unacceptable based on preferences for regional dialects, which may be a valid consideration in certain contexts, but is not a therapeutically useful one for speech-language pathologists. A critical review of studies of speech disorders associated with cleft palate found confusion and inconsistency between terms like intelligibility, acceptability, naturalness, severity, and proficiency (Whitehill, 2002). In order to deal with this issue, a more recent study on intelligibility and acceptability in cleft palate speech (Whitehill & Chun, 2002) adopted Southwood and Weismer (1993) definition of acceptability as speech that is functional and that fulfills at least the minimum requirements for a communicative need.

The literature on dysarthria often uses the terms bizarreness and naturalness. Initially, these terms were conceptualized as measures of severity of speech impairment and level of disability, respectively. Darley, Aronson, and Brown (1969, p. 251) define bizarreness as a "rating of degree to which overall speech calls attention to itself because of its unusual, peculiar, or bizarre characteristics." More recent definitions of naturalness have added an emphasis on features of prosody in their descriptions. Yorkston, Beukelman, Strand, and Hakel (2010, p. 288) state "speech is natural if it conforms to the listener's standards of rate, rhythm, intonation, and stress patterning, and if it conforms to the syntactic structure of the utterance being produced. It is considered unnatural or bizarre if it deviates from the expected or is unconventional in terms of these prosodic features." A similar definition by Yorkston, Beukelman, Minifie, and Sapir (1984) includes voice quality and intensity adjustments – independently from stress patterning – to the prosodic features of speech naturalness. These more recent definitions present naturalness as the polar opposite of bizarreness and assume that listener's perceptions of naturalness are primarily related to prosodic variables.

The interchangeable use of the terms naturalness, bizarreness, acceptability, and normalcy in the literature makes it difficult to compare the results of various studies in order to determine what perceptual criteria listeners may be using to determine ratings. One study of the dysarthria associated with Amyotrophic Lateral Sclerosis found strong correlations between all of these dimensions, suggesting that they may not be perceived as different qualities of dysarthric speech (Southwood & Weismer, 1993). Another major problem with these definitions is that they have not been validated in terms of the variables they purport to be primarily related to. There have been calls for research to determine what aspects of speech – and the relative importance of these aspects – contribute to naturalness ratings in order to better establish treatment priorities (Linebaugh & Wolfe, 1984; Metz et al., 1990; Southwood & Weismer, 1993; Yorkston et al., 1999).

The more specific descriptions of naturalness share an emphasis on prosodic features as an important aspect of speech naturalness, which is supported by the results of studies that examine naturalness in various speech disorders discussed in the following section.

Including prosody in the definition of naturalness may be important in order to differentiate naturalness from other perceptual measures like intelligibility. This approach is supported by studies in which disordered speech has been rated less natural than normal speech, even in the absence of segmental-level errors (Ingham & Onslow, 1985; Onslow & Ingham, 1987; Runyan et al., 1982; Sacco et al., 1992). This research suggests that listeners are basing their judgments of naturalness, in part at least, on suprasegmental aspects of speech. Although investigators have linked various speech characteristics to unnatural speech through acoustic and experimental studies (Bellaire, Yorkston, & Beukelman, 1986; Metz et al., 1990; Simmons, 1983; Whitehill & Chun, 2002), how these features interact in order to result in unnatural sounding speech is complex and only partly understood. Information about suprasegmental features often helps to explain the perceived lack of naturalness (Yorkston et al., 1999).

Naturalness has been investigated in many different types of speech and speech disorders. One major example is stuttering, as numerous studies have found that the speech of post-treatment adults is perceptually unnatural sounding when compared to normal speakers (Ingham, Gow, & Costello, 1985; Ingham & Packman, 1978; Metz et al., 1990; Onslow, Hayes, Hutchins, & Newman, 1992; Runyan & Adams, 1978, 1979). Especially striking are studies that have found that even in the absence of stuttering-like disfluencies, the speech of stutterers is still perceived as less natural sounding than the speech of non-stutterers (Ingham & Onslow, 1985; Onslow & Ingham, 1987; Runyan et al., 1982; Sacco et al., 1992). The only published study on acoustic aspects of speech and naturalness in stuttering found a significant relationship between voice onset time (VOT), sentence duration, and speech naturalness in the speech of individuals who stutter (Metz et al., 1990).

To date, there has been only one study on naturalness in the area of augmentative and alternative communication. Ratcliff, Coughlin, and Lehman (2002) looked at the effects of rate, pitch, and pause on ratings of speech naturalness on a particular type of voice output communication aid, DECTalk speech. The authors found that while listeners consistently found synthesized speech less natural than human speech and attributed their ratings to differences in pitch, rate, and pauses, only manipulations of speech rate and pause time resulted in significantly different naturalness ratings in subsequent experiments. The authors suggested that pitch may have not influenced naturalness ratings because only average pitch was manipulated, which did not produce perceptions of monotone speech or highly variable pitch.

Most research on cleft palate speech has focused on comparisons between its characteristics and intelligibility rather than naturalness (Whitehill, 2002). One recent study (Whitehill & Chun, 2002) looked at intelligibility and acceptability in speakers with cleft palate. The results indicated that intelligibility and acceptability are related, but not identical measures. Acceptability strongly correlated with nasality, while reduced articulatory proficiency had a much weaker effect.

Speech naturalness has been predominantly investigated in dysarthria and stuttering, although it has the potential to be a fruitful area of research in other speech disorders. The issue of naturalness in the speech of individuals with Aphasia or Apraxia of Speech (AOS) remains relatively unexplored, although both disorders have speech characteristics that could lend themselves well to naturalness ratings. Aphasics with right hemisphere damage characteristically are aprosodic, with reduced fundamental frequency and intensity contours throughout utterances and equal syllable durations (Kent & Rosenbek, 1982). Such

individuals have also been found to have reduced clause and utterance lengths (Cooper et al., 1984). One of the primary symptoms of AOS is prosodic disturbance. Apraxic speakers exhibit uniform syllable durations and fundamental frequency patterns (Kent & Rosenbek, 1982). Other prosody disturbances include slow speaking rate, reduced use of stress patterning, prolonged or inappropriate intersyllabic or interword pauses, and articulatory prolongation (Darley, Aronson, & Brown, 1975; Kent & Rosenbek, 1983; McNeil, Liss, Tseng, & Kent, 1990; Odell, McNeil, Rosenbek, & Hunter, 1990; Ryalls, 1981; Strand & McNeil, 1996; Wertz, LaPointe, & Rosenbek, 1984). In a study of an individual with AOS following a left hemisphere stroke, Tjaden (2000) found that equal syllable duration resulted in reduced speech naturalness. Similarly, the speech of hearing-impaired individuals is often characterized by prosodic disturbances. The speech of children with cochlear implants has been described as having inappropriate stress, pausing, and intonation (Lenden & Flipsen, 2007). Monotone speech and excessive variations in pitch have both also been observed in this population (Parkhurst & Levitt, 1978). Despite these well-known characteristics, researchers have mainly investigated the naturalness of speech output of hearing aids (Marzinzik, 2000) rather than the speech naturalness of the hearing-impaired themselves. One study (Osberger, 1987) examined the acceptability of subject's vowel productions in monosyllabic CVC words after systematic speech training.

In summary, when reviewing the literature on speech naturalness, several issues become apparent. The psychological validity of the measure has been shown through the reliably consistent judgments of naturalness on 9-point Likert scale (Ingham et al., 1985; Onslow, Adams, & Ingham, 1992), yet naturalness is often inconsistently defined, if defined at all. In addition, naturalness is at times used interchangeably or inconsistently with terms like normalcy, bizarreness, and acceptability. Another issue is the need for more research on what aspects of speech contribute to perceived naturalness (Linebaugh & Wolfe, 1984; Metz et al., 1990; Southwood & Weismer, 1993; Yorkston et al., 1999). Finally, methods for assessing naturalness vary widely between studies. In order to better understand the state of research on speech naturalness in communication disorders and quantify these impressions, this study looks at publications from the last 14 years in a systematic manner.

The present study aims to address three research questions: (1) how is speech naturalness measured across various studies; (2) are we adequately distinguishing naturalness from other global measures of speech output; and (3) how are we increasing our understanding of what aspects of speech contribute to naturalness judgments?

Method

Using the PubMed/MEDLINE, EBSCO, and ASHAWire databases, a literature search for the exact phrase "speech naturalness" was conducted. Articles considered for inclusion in the review were studies of communication and communication disorders published between 1990 and August 2018, in English, and in a peer-reviewed journal. This search resulted in 141 journal articles. Of these, 78 articles were either discarded as duplicates, considered not relevant to the current review because they did not include any measure considered to be a naturalness measure, or were tutorials rather than research articles. The

remaining 63 articles were selected to be read and coded using a coding sheet developed for this study.

The coding sheet was adapted from a systematic review of intelligibility assessment in cleft palate research (Whitehill, 2002) and addressed the following questions: (1) was another global measure of speech output (such as intelligibility) included; (2) was naturalness defined; (3) how was naturalness measured; (4) was there any attempt to explain naturalness deficits by examining the correlation between naturalness and other speech variables; (5) what disorder was the focus of the study; (6) what type of speech sample was used for assessing naturalness; (7) how many listeners were used to assess naturalness; (8) what type of listeners were used; and (9) was listener reliability reported?

All articles were coded by the authors of this study and then re-coded several months after the original coding. Intrajudge reliability for coding was above 97% for all categories. Where coding judgments differed, the coding was discussed and reviewed until a consensus was reached.

Results

63 articles covering the years 1990 to 2018 were reviewed. The articles covered a wide variety of non-disordered and disordered speech, as well as different modes of communication. The nature of the speech focused on in each study is summarized in Table 1.

The majority of studies (39 or 62%) concerned fluency disorders like stuttering and cluttering. Two studies (3%) looked at the speech produced by AAC devices. Alaryngeal speech and audiology were the focus of three (5%) and four (6%) of the studies each, respectively. Ten studies (16%) were concerned with motor speech disorders. One study (2%) looked at naturalness related to tracheostomies and voice each. The remaining three studies (5%) were focused on establishing normative values.

Other global measures used

45 (71%) of the studies did not examine any other global measure of speech output. The remaining 18 (29%) did examine at least one; some included two different global measures. These measures are given in Table 2.

In examining these measures, there is potential overlap with the measure of naturalness depending on how one defines naturalness. The difficulty with defining naturalness and potentially overlapping and inconsistent terminology will be addressed later.

Table 1. Primary focus of studies reviewed.

Primary Focus	Number of Studies
AAC	2
Alaryngeal Speech	3
Audiology	4
Fluency Disorders	39
Motor Speech Disorders	10
Normal Speech	3
Tracheotomy	1
Voice	1

Table 2. Global measures studied in addition to naturalness.

Global Measure	Number of Studies
Intelligibility	10
Listening effort	3
Acceptability	2
Normalcy	1
Speech effort	1
Listener comfort	1
Voice quality	2
Rhythmicity	1
Pleasantness	1

Definitions of naturalness

43 out of 63 studies (68%) did not include an operational definition of naturalness, although the measure was used as a variable. However, some of these studies may have given naturalness raters some sort of criteria that was not provided in the write up of the research. If this is the case, it poses a significant challenge to any who wish to test a study's reproducibility.

Those that did include definitions had varying definitions or utilized a negative definition of naturalness (e.g., as what naturalness is not – see Andrews et al., 2012). A few studies provided detailed descriptions of naturalness for their raters, including examples of both natural and unnatural speech (Craig et al., 1996). Some of the definitions given defined naturalness at least in part as containing few disfluencies and/or perceived effortless speech (Ingham, Warner, Byrd, & Cotton, 2006; McLeod & Searl, 2006; Tamplin, 2008). Other definitions included prosodic and suprasegmental aspects of speech, such as intonation, rate, loudness, rhythm, stress patterns, and voice quality (Eadie & Doyle, 2002; Spencer, Morgan, & Blond, 2009; Stocks, Dacakis, Phyland, & Rose, 2009; Tamplin, 2008; Yorkston, Hammen, Buekelman, & Traynor, 1990). One defined naturalness as a combination of intelligibility – another global measure – and speech production (Shikani & Dietrich-Burns, 2012). The remaining studies utilized extremely simple, and to some extent circular, definitions, stating that naturalness is essentially natural or normal speech (Coughlin-Woods, Lehman, & Cooke, 2005; Eadie, Doyle, Hansen, & Beaudin, 2008; Ratcliff et al., 2002; Tjaden, 2000; Tse, Wong, Ma, Whitehill, & Masters, 2013).

Method of measuring naturalness

The most common method of measuring naturalness was with a 9 point Likert scale, with the scale being used in 40 (63%) of the studies reviewed. In this scale, a score of 9 indicates highly unnatural sounding speech and 1 indicates highly natural speech, with scores of varying levels of naturalness available in between. The next most common method (used in 22 studies or 35%) was some other type of Likert scale, with scales varying from 4 to 100 points. Other methods include binary scales (4 or 6%), in which the choice was between natural and unnatural ratings, and Direct Magnitude Estimation (2 or 3%). In DME, listeners were provided with an example baseline and asked if rating samples were twice as natural, half as natural, etc., and assigned a score accordingly. Finally, one study

(2%) used qualitative descriptions of speech and determined naturalness from these descriptions.

Correlations between naturalness and speech variables

This factor was examined to determine the extent to which the relationship between naturalness and other variables has been investigated. It can be considered an indication of how researchers are attempting to increase our understanding of what listeners use to make their judgments of naturalness. The majority of studies reviewed (44 or 70%) did not attempt to correlate measurements of naturalness with another variable. The remaining 19 studies (30%) did include correlations with one or more of the following variables: temporal measures (including speech rate, sentence duration, word duration, diphthong duration, and intervals before and after words), stutter-free syllables per minute, frequency of part-word repetitions, phonation type, fundamental frequency, monopitch, fluency-inducing condition, speech effort, severity, dialect, percentage of syllables stuttered, and rhythmicity.

Speech sample used

There was a large amount of variability in how studies reported what kind of speech sample they used. It was not possible to categorize or count types of speech samples by study, since many types could possibly overlap without more detailed descriptions in studies' methods sections (e.g., a recorded telephone conversation would presumably involve conversational speech, but without a more detailed methods section one cannot be certain). Example descriptions of sample types are target words, pre/posttreatment, picture description task, stutter-free speech, sentences, monologue, spontaneous speech, reading passage, and conversational speech. Some studies defined the sample by the length of the sample or the type of recording (e.g., telephone, video, etc.) as well.

Number and types of listeners

Studies varied in the number of listeners used to assess naturalness, as shown in Table 3. All but one study reported how many listeners were used. A majority of studies used either six to twenty listeners or five or fewer listeners (21 or 33% each). Some studies used as many as over 50 listeners (9 or 14%).

The majority of studies (26 or 41%) used naive listeners. 25 studies (40%) used listeners who had some expertise in speech and language, either because they were practicing speech-language pathologists, students (graduate or undergraduate) in speech-language pathology,

Table 3. Number of listeners.

Number of Listeners	Number of Studies
5 and under	18
6 to 20	21
21 to 49	14
over 50	9
unspecified	1

Table 4. Types of listeners.

Type of Listener	Number of Studies
Naïve	26
Expert	25
Mixed	10
Unspecified	2

Table 5. Reports of listener reliability.

Reliability Reported	Number of Studies
Inter-rater only	8
Intra-rater only	2
Inter- and intra-rater	34
None	19

and/or trained listeners. Ten (16%) studies used a mixture of listeners (i.e., a panel of speech-language pathologists and a panel of naıve listeners). Only two studies did not specify the type of listener. A summary of types of listeners used is provided in Table 4.

Reliability reports

44 of the studies reviewed (70%) reported the reliability of their naturalness measurements. Studies were included in this number if they reported interjudge and/or intrajudge reliability; a majority of studies included both (34 or 54%). A summary of reliability reporting in the studies is given in Table 5. 19 articles (30%) included no information about the reliability of naturalness measures.

Discussion

63 studies published in recent years that included the measurement of speech naturalness were identified and reviewed. The studies had a wide range of focus, covering everything from normal speech to AAC to fluency disorders. However, several significant concerns were raised due to this review.

One concern relates to the reliability and validity of measurements. The importance of including interrater and intrarater reliability in measuring speech has been stated by other authors (D'Antonio & Scherer, 1995; Wyatt et al., 1996). Despite this, 30% of the studies reviewed included no reports on the reliability of their measurements. Although most of the studies (54%) included both inter- and intrarater reliability, the lack of reporting could cast doubt on how dependable the measurements were. Validity of measurements is related to construct validity, which is the extent to which a tool measures an underlying concept. This is difficult, or even impossible, to ensure when a standardized definition of the concept does not exist. While this problem is not limited to just the concept of speech naturalness in communication disorders, it is very present, as shown by the review. 68%, a majority of the studies reviewed, did not include a definition of naturalness, despite measuring it. Those that did provide a definition utilize varying definitions, often

depending on the speech disorder involved. Unfortunately, this makes it impossible to compare results across studies, as one cannot be certain that the same entity was measured.

The lack of unified definition relates to the tension between parsimony and thick description when studying a real-life phenomenon like speech naturalness. The two do not necessarily need to be mutually exclusive in any one theory or explanation. Yet there are situations in which a more parsimonious approach, in which a more superficial description leads to easier understanding, is more appropriate and other situations in which it would be more appropriate to err on the side of accuracy by attempting a more complex description of the subject of study, even if it is more difficult to grapple with. Given the advances in the field of speech-language pathology and current emphasis on evidence-based practice, it seems that the latter approach here is more than justified. It may be possible to have one very broad definition of speech naturalness that can cover all types of speech disorders, but it is likely that much more work has to be done to make more accurate and detailed definitions of speech naturalness according to disorder. Either way, researchers and clinicians would benefit from accurate, agreed upon definitions.

Another concern was that the type of speech sample used for measurement varied widely and was often not possible to determine exactly due to lack of detail in method descriptions. From this review, it can be seen that a large variety of methods are used to measure naturalness and there are no recommended protocols. Unfortunately, the lack of detailed description makes replication studies, a basic tool of science, unfeasible. In addition, there is some indication that different types of speech samples (e.g. reading passages versus spontaneous speech) elicit different naturalness ratings by listeners (Klopfenstein, 2016). Until the relationship between speech sample type and naturalness ratings is better understood, future research should report detailed descriptions of methods used so that comparison of results and replications studies are possible.

A final aspect of concern relates to the lack of attempt to relate naturalness and other aspects of speech. Our understanding of what listeners use to evaluate naturalness is still very limited, as very few studies include correlations. Most studies did not attempt to determine its relationship to other variables reported (70%), despite naturalness being included as a measure. A better understanding of this relationship could improve therapeutic decision-making, if targeting intelligibility before naturalness, as suggested by Whitehill (2002). Another possibility is that with this insight clinicians could better predict how different treatment approaches, depending on what is targeted, affect naturalness and vice versa.

In summary, the review indicates that speech naturalness is an object of study in many subfields of communication disorders. Each of these fields has the potential to serve as an important contributor to understanding what exactly influences perceptions of naturalness, a measure shown to be psychologically valid but difficult to describe thus far. Unfortunately, the lack of consistency between methods used in different studies means that comparing findings is difficult at best. Future studies should more carefully report methods and operational definitions used and more studies examining the relationship between naturalness and other speech variables in a variety of communication disorders are greatly needed.

Disclosure statement

No potential conflict of interest was reported by the authors.

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