

Speech intelligibility measurement

A latent variable approach on utterances' transcriptions

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Abstract

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1 Introduction

Intelligible speech can be defined as the extent to which the elements in a speaker’s acoustic signal, e.g. phonemes or words, can be correctly recovered by a listener [11, 14, 21, 22]. Intelligible spoken language carries an important societal value, as its attainment requires all core components of speech perception, cognitive processing, linguistic knowledge, and articulation to be mastered [11]. In that sense, *speech intelligibility* is considered a milestone in children’s language development, and more practically, it is qualified as the ultimate checkpoint for the success of speech therapy, and the ‘gold standard’ for assessing the benefit of cochlear implantation [4].

Multiple approaches can be taken to quantify *speech intelligibility* [1, 2, 10, 13], but among them, *objective rating* methods on stimuli recovered from spontaneous speech tasks have received a especial attention [2, 13]. In objective rating methods, listeners transcribe children’s utterances orthographically (or phonetically), and use such information to construct an intelligibility score. In that sense, the method infers intelligibility from the extent in which a set of transcribers, can identify the word contained in an utterance [2].

As the literature suggests, because objective rating procedures do not hinge in the use or production of a *subjective rating scale*, i.e. a scale based on a personal perception of the child’s intelligibility, it is thought it can produce more valid¹ and reliable² scores than any other available procedure [2, 8]. Moreover, the previous advantage is further emphasized by the use of utterances recovered from spontaneous speech tasks, as these are thought to have a greater level of ecological validity, compared to any other type of collected stimuli, e.g. contextualized utterances or reading at loud tasks [10, 6].

Although the literature conceptualize *speech intelligibility* as in the previous paragraph [2], and further suggest multiple perspectives and approaches to measure it [1, 2, 13], the statistical approach used to test reasearch hypothesis to authors opinion is lacking of ... knowledge no paper tries to estimate the individuals’ intelligibility score. Moreover, no paper test their research hypothesis directly on an intelligibility outcome, but rather on surrogate measures of it. For instance, Flipsen [10] uses

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We believe this paper make three specific contributions to the understanding of the factors that drive the intelligibility of spoken language. First, we develop a novel analysis using a latent variable approach [7]. More specifically, we model *speech intelligibility* as a latent variable that can be inferred from the entropy replicates. This method offers three specific benefits. On the one hand, the method ‘constructs’ an intelligibility score, which in turn, allow us to test different hypothesis and even make individual comparisons at the appropriate level. On the other hand, it allow us to control for different sources of variation. This is particularly important as, by failing to account for the appropriate hierarchies in the data, we could be ‘manufacturing’ false confidence in the parameter estimates, leading us to incorrect inferences [16]. Finally, the method also provides a ‘criterion’ on how reliable are the entropy replicates to measure speech intelligibility.

Second, we use Directed Acyclic Graph (DAG) [18, 5] to depict all the relevant variables though to influence speech intelligibility. We describe in detail our causal and non-causal hypothesis, and supplement our description with a causal diagram. The benefit of the method lies, not only, in that it makes the assumptions of our hypothesis more transparent, but also allow us to derive statistical procedures from the aforementioned causal assumptions [16, 24, 19].

Accompanying the intelligibility assessment methods, the literature supply a myriad of factors that are thought also contribute to the (under)development of intelligible spoken language [17, 3, 12, 9]. Among these are audiology related factors, such chronological age, age at implantation, the duration of device use, *hearing age*, bilateral or contralateral cochlear implantation, and the children’s preoperative and postoperative hearing levels. On the other hand, there are also child related factors, such as the cause of the hearing impairment (genetic, infections), additional disabilities (mental retardation, speech motor problems), and gender. Finally, there are also environmental factors, such as communication modality.

Third and final, we wrap the analysis procedure under the Bayesian framework, providing the assumptions, and the steps required to reproduce the computational implementation of the models.

Considering all of the above, this paper seeks to investigates the speech intelligibility levels of normal hearing (NH) versus hearing-impaired children with cochlear implants (HI/CI). For that purpose, ten

¹validity is understood as the extent to which scores are appropriate for their intended interpretation and use [15, 20].

²reliability is though as the extend to which a measure would give us the same result over and over again [20], i.e. measure something, free from error, in a consistent way.

utterances recordings, from thirty two NH and HI/CI children, were selected from a large corpus of *spontaneously spoken speech* collected by the CLiPS research center. Additionally, we set up an experiment, where one hundred language students transcribed each stimuli to the Qualtrics environment [23]. Finally, the transcriptions were transformed into an entropy measure per utterance, which served as our outcome variable.

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