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Citation for published version:

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Peer reviewed version

Published In:
Speech Prosody 2016

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Evaluating comprehension of natural and synthetic conversational speech

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Abstract

Current speech synthesis methods typically operate on isolated sentences and lack convincing prosody when generating longer segments of speech. Similarly, prevailing TTS evaluation paradigms, such as intelligibility (transcription word error rate) or MOS, only score sentences in isolation, even though overall comprehension arguably is more important for speech-based communication. In an effort to develop more ecologically-relevant evaluation techniques that go beyond isolated sentences, we investigated comprehension of natural and synthetic speech dialogues. Specifically, we tested listener comprehension on long segments of spontaneous and engaging conversational speech (three 10-minute radio interviews of comedians). Interviews were reproduced either as natural speech, synthesised from carefully prepared transcripts, or synthesised using durations from forced-alignment against the natural speech, all in a balanced design. Comprehension was measured using multiple choice questions. A significant difference was measured between the comprehension/retention of natural speech (74% correct responses) and synthetic speech with forced-aligned durations (61% correct responses). However, no significant difference was observed between natural and regular synthetic speech (70% correct responses). Effective evaluation of comprehension remains elusive.

Index Terms: evaluation, comprehension, conversational speech, statistical parametric speech synthesis

1. Introduction

The goal of this work is to develop more ecologically-valid evaluation techniques that go beyond isolated sentences and measure comprehension of synthetic speech compared to natural speech. Modern text-to-speech synthesis systems (Statistical Parametric Speech Synthesis (SPSS)) produce speech that is comparable to natural speech in terms of intelligibility [1, 2]. Intelligibility, in this context, is mostly measured by transcription of semantically unpredictable sentences (SUS). However, the suprasegmental factors (duration, intonation, accents, pauses, etc.) that play a large role in comprehension do not figure prominently in the decoding of SUS (meaningless sentences in isolation). Therefore, this type of intelligibility may not be a good indicator of the comprehensibility of synthetic speech.

Prosody (suprasegmental factors) is arguably the defining difference between natural and synthetic speech. The importance of prosody for natural speech comprehension has been extensively investigated (see [3] for an overview). At the same time, the lack of appropriate prosody in TTS has been shown to affect speech intelligibility, response latencies and comprehension [4, 5, 6]. The effect of suprasegmental aspects on the comprehension of speech is not measured effectively by either MOS or SUS. The evaluation proposed in this paper attempts to fill this void.

A further motivation for developing better evaluation methods is the type of data that is increasingly being exploited as a source of speech data for SPSS – specifically ‘found data’ such as audio books or broadcast media data [1, 7, 8, 9, 10]. This is used, for instance, to create more expressive synthesis [7, 8] or for multi-lingual lightly-supervised TTS [9]. However, the evaluation methods needed to measure the success of these approaches are still lacking.

The data considered here – Desert Island Discs interviews – have interesting and meaningful prosody, are engaging to listen to, and are full of information. The evaluation paradigm used to measure comprehension is multiple-choice questions. The next section discusses prior work in this field and how our study fits with this literature.

2. Prior work

Attempts at developing comprehension tests to evaluate speech synthesis have a long history. Comprehension or comprehensibility of synthetic speech has been measured in a variety of different ways ranging from sentence verification tasks [11, 12] via immediate recall [13, 5], word-monitoring [14] multiple-choice questions [15, 16, 17, 18, 6, 19] and a summarization task [20], to computing math sums [21].

Previous attempts (in the 80s and 90s) at measuring comprehension using post-perceptual measures often did not show significant differences in comprehension between synthetic (formant-based) and natural speech [15, 16, 18]. (See [22] for a comprehensive review of comprehension of synthetic speech produced by rule.) [11] suggests this is due to the type of tests used. By using post-perceptual measures and multiple-choice questions or recall measures, subjects are encouraged to exploit real-world knowledge to solve the task. [11] argues that more sensitive measures are needed that measure the online perception process and proposed using the sentence verification task (SVT). Online measures of perceptual processing show that there are perceptual difficulties in interpreting high quality synthetic speech [11, 12] which disappear by the time the entire comprehension process has run its course [23].

Online methods generally use sentence-level materials which have been carefully constructed, for instance, to control for predictability [11] or text difficulty [14]. Evaluation techniques that are suitable for found data need to be able to evaluate longer stretches of speech, e.g., dialogues or stories. Therefore, online methods do not appear to be appropriate for e.g., Desert Island Discs data.

More recent studies investigating comprehension of synthetic speech (unit-selection and SPSS) revisit the use of multiple-choice questions [6, 19]. In [6] the comprehension of natural and unit-selection synthetic speech is compared using mainly multiple-choice questions. They found a significant difference in comprehension with synthetic speech scoring lower,
whereas intelligibility, measured using SUS, was equal between the two types of speech. Modifying the synthetic speech by inserting pauses between intonational phrases, thereby approximating the pauses in natural speech, removed the difference in comprehension between natural and synthetic speech. 

The results in [19] and to a certain extent [6] fit an interpretation that post-perceptual tests are possibly not sufficiently sensitive to measure differences in comprehension. Nevertheless, we feel the post-perceptual approaches to measuring comprehension are not yet exhausted. There are a number of factors that we suspect may be affecting the sensitivity of post-perceptual tests. Firstly, the length of the speech material might be too short, i.e., 12–31 words [16, 17], or under 2 minutes [18]. Secondly, the content might not be prosodically interesting enough, i.e., rather boring sentences selected from news articles [19] or reading comprehension tests [18]. Finally, the questions asked may not be of the right type, i.e., higher-level questions can be answered even with poor intelligibility scores [19].

Our experiment is different to previous work in terms of the type and duration of the speech material and the type of questions. The Desert Island Discs material that we use is:

- prosodically rich; it comprises interesting and engaging interviews with comedians,
- 10 minutes long for each interview,
- tested using multiple choice questions which are surface structure or low-proposition questions, i.e., the participants are required to recall exact wording or detailed information about the speech content, thus not additionally relying on real-world knowledge.

Our expectation is that controlling these factors should increase the sensitivity of post-perceptual testing for measuring differences in comprehension between synthetic and natural speech.

3. Method

3.1. Evaluation data

“Desert Island Discs” is a BBC Radio 4 programme [24]. The programme is in the format of an interview, in which a guest is invited by Kirsty Young (the host) to choose the eight recipes using standard purpose-recorded speech databases. A single-speaker Scottish-accented female database was used to train the voice of the interviewer, and single-speaker British male and female databases were used for the voices of the guests. Note that the same TTS (text-to-speech) model was used for both male guests. The databases consisted of 238, 64 and 96 minutes of speech, respectively, excluding silent portions at the beginning and ends of sentences, and were sampled at 48 kHz.

Training of both synthesis front-ends and acoustic models broadly followed the description given in [25]. Accent-specific variants of the Comblex lexicon [26] were chosen to match each of the TTS voice talents’ accents. The speech data was automatically aligned with text-derived annotation using forced alignment with 5-state hidden Markov models allowing for the insertion of pauses between words.

Deep neural networks (DNNs) were trained to predict both the duration of phones and frames of acoustics. The duration models were trained to map from phone-level inputs ex-

<table>
<thead>
<tr>
<th>1. How many people have tried the cross-channel swim?</th>
</tr>
</thead>
</table>
| • 7000  
| • 7500  
| • 9000  
| • 6000  |

<table>
<thead>
<tr>
<th>2. What did David not mention buying in charity shops?</th>
</tr>
</thead>
</table>
| • suits  
| • coats  
| • shirts  
| • ties  |

Table 1: Example questions from the David Walliams interview. The correct answer is highlighted using *italics*.
Table 2: Durations (in minutes and seconds) of natural and synthetic interview excerpts used.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>S</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>DW</td>
<td>9:56</td>
<td>9:25</td>
<td>9:28</td>
</tr>
<tr>
<td>SC</td>
<td>10:00</td>
<td>11:13</td>
<td>10:13</td>
</tr>
<tr>
<td>VW</td>
<td>10:08</td>
<td>12:25</td>
<td>10:02</td>
</tr>
</tbody>
</table>

Table 3: Number and fraction of correct responses across speech types (columns) and interviews (rows).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>S</th>
<th>M</th>
<th>All types</th>
</tr>
</thead>
<tbody>
<tr>
<td>DW</td>
<td>164/240</td>
<td>181/240</td>
<td>134/240</td>
<td>479/720</td>
</tr>
<tr>
<td>SC</td>
<td>176/240</td>
<td>144/240</td>
<td>147/240</td>
<td>467/720</td>
</tr>
<tr>
<td>VW</td>
<td>190/240</td>
<td>181/240</td>
<td>157/240</td>
<td>528/720</td>
</tr>
<tr>
<td>All int.</td>
<td>530/720</td>
<td>506/720</td>
<td>438/720</td>
<td>1474/2160</td>
</tr>
</tbody>
</table>

Table 4: Differences in the overall rate of correct response between speech types, and adjusted p-values for a null hypothesis that the difference is zero.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>N vs. S</th>
<th>N vs. M</th>
<th>S vs. M</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference</td>
<td>3.3%</td>
<td>13%</td>
<td>9.4%</td>
<td></td>
</tr>
<tr>
<td>Adjusted p-value</td>
<td>0.18</td>
<td>&lt;10^-6</td>
<td>4.0*10^-4</td>
<td></td>
</tr>
</tbody>
</table>

3.3.2. Speech generation

Stimuli for conditions S and M were synthesised from a manually-checked transcript of the data. Some care was taken to ensure that false starts and filled pauses were recorded in the transcripts. The audio was segmented into sentences, each assigned to the guest or the host speaker. The transcripts were passed through the TTS front-ends, and the resulting annotation was used in two different ways, depending on the condition: For the completely synthetic condition S, the front-end’s predictions of sentence-internal pauses were used directly, durations and then acoustic features were predicted with the two DNNs for each voice. For the duration-modified condition M, the forced alignment models used to obtain aligned training data were used to align the test-set annotation with the interview audio. Note that for this reason, the alignment model used 12-dimensional MFCCs plus energy with dynamic features appended, and utterance-level cepstral mean normalisation. These are different from the synthesis features, but extracted at a frame rate compatible with them (5 ms), and are sufficiently speaker-independent to produce an alignment which performed well on the speakers in the Desert Island Disc data, as long speech was free of background noise. Ideally, the annotation created in this way would allow the generation of speech which is synthetic in all respects, except for segmental durations and placement of sentence-internal pauses.

After sentences were generated by the appropriate model for each speaker, they were concatenated into whole-interview extracts for use in the listening test. Inter-sentence pauses having the same duration as the natural ones but consisting of pure silence were inserted between sentences during the concatenation. Table 2 lists the durations of the resulting interview excerpts under the different conditions.

4. Results

This section presents our experimental results and analysis; deeper discussion and interpretation is reserved for Section 5.
5. Discussion

The goal of the evaluation was to measure comprehension differences between synthetic and natural speech using a post-perceptual approach. Our results paint a complex picture. Overall, it is clear that subjects perform significantly worse on modified synthesis (M) than on regular synthetic or natural speech, even though one might have expected it to fall between S and N due to the natural durations used. We suspect this may be due to mismatch between the training and test data. In particular, acoustic models learned on the carefully paced read-speech training material may not produce highly intelligible or comprehensible speech when shoehorned into the spurt-like duration structure of the interview speech. In addition, overlapping speech and laughter tended to have a very detrimental effect on the automatic alignment, which may have played a role as well.

While average comprehension performance on regular synthetic speech (S) is 3.3% lower than on natural speech N, this difference is not statistically significant. These results suggest that post-perceptual tests at present are not sensitive enough to easily identify comprehensibility differences, even when using prosodically rich conversational material.

The detailed performance breakdown in Table 3 presents a complex pattern of performance differences across interviews and speech types. The numbers suggesting that synthesised (S) SC is much more challenging than synthesised DW, compared to their respective natural (N) interviews, may appear difficult to reconcile with the fact that the synthetic voice used for both these interviewees is exactly the same. However, while large in magnitude, most of the differences between N and S in the table are not significant due to the small sample sizes prior to pooling. This and other indications suggest that much of the observed complexity may simply be attributable to random variation.

In their comments, many participants said that synthetic speech was more difficult to focus on, but also that despite this they found the task doable, which is supported by the objective data. Two participants even described being ‘nauseated’ by listening to the synthetic speech. Taken together, this suggests that the experience of listening to extended segments of synthesised speech is quite degraded compared to natural speech, though not in a manner that stands out in our objective test.

In future work, we will investigate our question sets in more detail. The segmental intelligibility of the three types of speech will be measured by giving listeners a multiple-choice question and then playing the relevant fragment of speech containing the answer to the question. This will indicate whether M was simply less intelligible than S, or if other factors are at play as well.

Developing ecologically-relevant evaluation techniques for synthetic speech is still very much a work in progress. The type of scenarios we increasingly need novel techniques for are for example: “How to evaluate a voice built on found data like Desert Island Discs?” or “How should audio books or conversational voices be evaluated?” Recent years have seen a few attempts to develop evaluation techniques for these scenarios, e.g., evaluation of the personality of synthetic voices [29], psycholinguistic studies into filled pauses for synthetic speech [30] and the evaluation of intonation [31]. However, there is still a lot of room to investigate and design more appropriate evaluation strategies.

Acknowledgements This work was supported by the EPSRC under Programme Grant EP/I031022/1 (Natural Speech Technology). The NST research data collection may be accessed at http://datashare.is.ed.ac.uk/handle/10283/786. The data for this paper will be made publicly available upon paper acceptance.
6. References


