Rhythm in the speech of a person with right hemisphere damage: Applying the Pairwise Variability Index

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Abstract

Although several aspects of prosody have been studied in speakers with right hemisphere damage (RHD), rhythm remains largely uninvestigated. This study compares the rhythm of an Australian English speaker with right hemisphere damage (due to a stroke, but with no concomitant dysarthria) to that of a neurologically unimpaired individual. The speakers' rhythm is compared using the pairwise variability index (PVI) which allows for an acoustic characterisation of rhythm by comparing the duration of successive vocalic and intervocalic intervals. A sample of speech from a structured interview between a speech and language therapist and each participant was analysed. Previous research has shown that speakers with RHD may have difficulties with intonation production, and therefore it was hypothesised that there may also be rhythmic disturbance. Results show that the neurologically normal control uses a similar rhythm to that reported for British English (there are no previous studies available for Australian English), whilst the speaker with RHD produces speech with a less strongly stress-timed rhythm. This finding was statistically significant for the intervocalic intervals measured ($t(8)=4.7$, $p<0.01$), and suggests that some aspects of prosody may be right lateralised for this speaker. The findings are discussed in relation to previous findings of dysprosody in RHD populations, and in relation to syllable-timed speech of people with other neurological conditions.

Keywords : rhythm, prosody, RHD, PVI, stress-timed.

Introduction

Defining and measuring rhythm.

The definition of rhythm is somewhat nebulous, probably because rhythm works differently in different languages, and as described below, acoustic cues to rhythm have been difficult to locate. Trask (1996, p. 311) however, defines rhythm as 'the perceptual pattern produced in speech by the occurrence at regular intervals of prominent elements'. The prominent elements that Trask refers to may be either stresses or syllables, and on this basis early descriptions of speech rhythm, such as that by Pike (1945), distinguish two types of rhythm known as stress-timing and syllable-timing. Abercrombie (1967) states that all languages fall into one of these two categories. For example, British English and Dutch are classified as being stress-timed. In stress-timed languages, speakers seem to leave roughly equal durations between stressed syllables. This gives rise to feet (another unit of rhythm, usually defined as consisting of one stressed syllable followed by any number of unstressed syllables) of roughly equal duration, but individual syllables within the foot may vary greatly in duration. Syllable-timed languages, such as French and Spanish, on the other hand, tend to exhibit syllables which sound to be of roughly equal duration, but display less of a durational alternation between stressed and unstressed syllables.

The chief problem with these classical descriptions of rhythm is that they rest heavily on the impressionistic perception of the listener. Instrumental studies (such as those by Roach, 1982 and Dauer, 1983), by contrast, have consistently found that feet are not isochronous (equally timed) in so called stress-timed languages, and that syllables are not isochronous in syllable-timed languages. As a result, researchers' views of rhythm have changed in two fundamental ways. Firstly, most researchers, following Dauer (1983), now see rhythm as a continuous variable. Instead of all languages being classified as stress- or syllable-timed, they are now believed to fall on a continuum between these two extremes. Secondly most authors now claim that languages exhibit only perceptual isochrony, whereby syllables or feet sound to be of equal duration to the listener without being equal acoustically. However, the basis of this perceptual isochrony still needs to be explained, even if the acoustic measures of syllable and foot duration are inadequate for the task.

In recent years, researchers have begun to use new measures to investigate the basis of perceptual isochrony. The two most developed of these proposals describe rhythm by using measures of the relative durations of vowels and consonants (although modelling of rhythm using coupled oscillators (e.g. Barbosa, 2002 and references therein) is also a useful viewpoint that links rhythm more explicitly to other types of motor movement). One proposal by Ramus, Nespor and Mehler (1999) suggested the use of three measures: the standard deviation of vowel, and consonant durations, and the proportion of the total utterance comprising vowel durations. These measures were shown to be significantly different when applied to the perceptually and classically defined syllable- and stress-timed languages. The Pairwise Variability Index (PVI) popularised by Low, Grabe and Nolan (2000) makes use of a similar comparison to that of Ramus *et al*. Essentially the PVI compares the duration of successive vocalic and intervocalic durations. Using the PVI, Low *et al*. (2000) showed that Singapore English is more syllable-timed than British English, and Grabe and Low (2002) further demonstrated that the PVI gives significantly different results when applied to those languages classically described as syllable- or stress- timed.

These metrics of speech rhythm work on the assumption that rhythm arises from the phonological structure of a language (Grabe and Low, 2002, p. 519). The classically stress-timed languages will show greater variety in vowel durations than syllable-timed languages because they have a greater degree of vowel reduction. Because unstressed words will exhibit vowel reduction, and stressed words will not, and because stressed and unstressed syllables tend to alternate in these languages, there should be a large difference between successive vowel durations. In addition stress-timed languages will tend to allow more types of onsets (the consonants in a syllable before the vowel) and codas (the consonants in a syllable after the vowel), including complex onset and coda clusters, so will also show more intervocalic durational variability than perceptually syllable-timed languages.

One of the major differences between the measures proposed by Ramus *et al*. (1999) and Low *et al*. (2000) is their treatment of speech rate (see White and Mattys, in press, for a review). Ramus *et al*. (1999) build speech rate into their measure by asking speakers of different languages to read utterances of similar duration. Low *et al*., on the other hand, add a normalisation measure to their equations. Specifically this normalisation is applied to vocalic intervals as these are considered to be most affected by speech rate (Gay, 1978). Low *et al*. demonstrate that, of the two measures, the PVI is more robust at different speaking rates.

The PVI measure has so far been used to describe the rhythm of languages and varieties and make comparisons between them. Languages are then often placed on a scale according to their PVI value and compared to the classical descriptions of stress- and syllable-timing. Likewise, different varieties with in a language may also be compared, as demonstrated by Low et al's (2000) comparison of Singaporean and British English, described above. The present study, however, makes novel use of the PVI by comparing the rhythm produced by a person with RHD to that of a normal control.

Prosody in speakers with RHD

Although rhythm has been little studied in the speech of speakers with RHD, many other prosodic features, particularly intonation, have been the subject of extensive investigation. The impetus for the study of prosody in RHD populations comes from clinical observations that prosody is disrupted in these individuals (Behrens 1988; Ross, 1981). The disruption is often referred to as 'dysprosody' following Monrad-Krohn's (1963) term for a similar phenomenon in a patient with damage to the left frontal region of the brain (replacing the term aprosodia from his 1947 work).

However, the findings about the right hemisphere's role in prosody are mixed and often differ with respect to the <u>function</u> of prosody under study. Many researchers propose a binary division between linguistic and affective prosodic functions (see Roach, 2000, particularly chapters 18 and 19, for a review of the different functions of prosody, especially intonation). Linguistic functions of prosody include: stress differences between otherwise identical words (`record (noun) and re`cord (verb)), the marking of syntactic boundaries (old men (,) and women were there), and the indication of the speaker's illocutionary act (question vs. statement). The affective, or paralinguistic functions of prosody inform the listener about the emotions and attitudes of the speaker.

The lateralisation of different prosodic functions has also been a focus of research. Baum and Pell (1999, see p 583) summarise four different hypotheses for the lateralisation of prosody in the brain. The first hypothesis is that all functions of prosody are lateralised to the right, whilst the second says that only affective prosody is right lateralised whilst linguistic functions are associated with the left hemisphere. A third hypothesis is that there is no lateralisation, as the neural basis of prosody is subcortical, whilst the fourth states that individual prosodic cues can be independently lateralised.

Baum and Pell (1999, see p 592) go on to state that the evidence for a strict lateralisation of prosody to the right hemisphere is equivocal. The results of existing studies are mixed and seem to depend a great deal on whether the analysis undertaken is perceptual or acoustic, whether affective or linguistic prosody is tested and whether production or comprehension is the focus of the study. Additionally, few studies look at linguistic and affective prosody in the same participants. In conclusion to their review of the evidence for the neural bases of prosody, Baum and Pell (1999, p602) report only "weak support of differential lateralization of prosodic cues as an index of their linguistic or affective communicative function in speech".

Despite the large body of work on prosodic lateralisation, one aspect of prosody that has been little described in the literature on RHD is the production or perception of rhythm. Rhythm is studied less frequently than stress or intonation in both normal and clinical populations. This is likely to be because, for reasons explained above, rhythm is difficult to define and measure. Although rhythm is little studied it in fact offers a different level of prosody for examination. Rhythm, as it is examined here, cannot be defined as having either a linguistic or affective function. Rather rhythm is a prosodic characteristic of a speaker's native language in much the same way as the phoneme inventory and the phonotactics are characteristic of the native language at a segmental level. Rhythm's phonological status therefore allows for the analysis of an aspect of prosody which has neither a linguistic or affective function. The investigation of rhythm is, therefore, a crucial addition to our understanding of prosodic processing in speakers with RHD.

Purpose

This study aimed to investigate the little studied area of rhythm in an RHD patient by applying the PVI. As there are no PVI norms for Australian English the data from the patient with RHD was compared to that of a neurologically normal control. It was hypothesised that there may be some disruption to rhythm in the speech of the RHD patient on the basis of studies which demonstrate deficits in other prosodic features (such as intonation) for this population. However, the direction of any change, be it to a more syllable or stress-timed rhythm, was not predicted. In addition, as rhythm is neither a linguistic or affective aspect of prosody, and because there is no clear evidence that all aspects of prosody are right lateralised, it was also possible that no effect would be found. This study aimed, therefore, to test whether there are any differences between the rhythm of a person with RHD and a neurologically normal control, and to see if differences manifest themselves as a tendency towards more syllable-timed or more stress-timed rhythm.

Method

Participants

Participants were both males and native, monolingual speakers of Australian English. They had both lived all their lives in Western Australia. Participants were matched on educational levels with both participants having completed 12 years of education.

The control participant was recruited from a local sporting club to participate in a larger study on the impact of RHD on gesture production (Cocks, Hird & Kirsner, 2007). He was 64 at the time of the study.

The participant with RHD was also recruited for a larger study on gesture production following right hemisphere damage (Cocks et al., 2007). He was aged 51 at the time of the study. He had suffered a large right middle cerebral artery ischaemic stroke 5 months prior to the recording. An initial assessment of the participant's visuo-spatial ability was carried out using the WAIS-III block design (Wechsler, 1997), WAIS-III picture arrangement (Wechsler, 1997), Raven's Progressive Matrices (Raven, 1985) and Symbol Digit Modality Test (Smith, 1973). The participant's scores were compared to the group of 19 control participants in the larger study and where possible the mean score of the population. The participant obtained significantly lower scores on all tests suggesting that the participant had impaired visuo-spatial abilities. Bisection of horizontal lines and Cancel C & E were used to determine whether the participant had hemi-spatial neglect. The participant performed poorly on both these tasks consistent with a hemi-spatial neglect diagnosis. The participant was referred to the speech pathology department due to impaired prosody, inappropriate topic choice, impaired discourse structure and tangential speech.

On referral, an oral musculature examination (OME) was carried out to identify any weakness or incoordination in oral musculature. The OME did not indicate any difficulties. The participant did not demonstrate any difficulties with phonation, resonance or articulation that would be consistent with a diagnosis of dysarthria. The participant and the medical team did not report any symptoms consistent with dysphagia or vocal fold dysfunction, however the client's vocal folds were not formally examined.

Initial assessment of the participant's prosody was made by measuring pitch variation and mean pitch in approximately 30 minutes of conversation using PRAAT 4.0 (Boersma & Weenink, 2002). The participant's scores were compared to a group of 19 control participants and found to be within the normal range. These results are presented elsewhere by Cocks and colleagues (2007). However, despite the measures of intonation, including pitch variation and mean pitch, being within the normal range, the speech pathologist indicated that the client's prosody sounded impaired.

Materials

The recordings used for this analysis were taken from a 30 minute structured conversation between a speech pathologist and the participant. The speech pathologist was not known previously to the participants. The conversation sample was collected for use in a larger study on the impact of right hemisphere damage on gesture and prosody (Cocks et al., 2007). The conversation consisted of one personal narrative, 2 procedural narratives, 2 emotional narratives and 3 comic book descriptions. For the purpose of this investigation only part of the section of the discourse, one of the emotional narratives, in which the participant was asked to describe an event that evoked a positive emotion was analysed.

Recording Procedure

The recording of the control participant was collected in the participant's own home, while the recording of the RHD participant was collected while the participant was an inpatient in a rehabilitation hospital. Extracts of the conversations are given in appendices 1 and 2. The recordings were digitised using the acoustic analysis program PRAAT 4.0 (Boersma & Weenink, 2002) at a sampling rate of 11025Hz with 16 bits resolution.

Applying the PVI

The PVI works by firstly measuring the durations of vocalic and intervocalic intervals in a sample of speech, as determined by the presence and absence of formant structure respectively. Sonorant consonants which, like vowels, have a formant structure are included in the intervocalic sections whenever they can be clearly identified by spectral changes. As the PVI is "based on acoustic rather than phonological principles" (Whitworth, 2002, 189) vocalic and intervocalic intervals may encompass word and syllable boundaries. So, for example, in the phrase 'the elephant ran', shown diagrammatically in Figure 1, the first intervocalic (consonantal) section consists of the single segment /ð/. The first vocalic element, however, consists of the vowel at the end of 'the' and the vowel at the start of 'elephant'. The pattern then alternates with one vowel and one consonant in each successive interval until the sequence of three consonants from the coda of ‘elephant’ and the onset of ‘ran’, which is treated as a single intervocalic interval.

Insert figure 1 about here

In essence the raw intervocalic PVI (rInt) compares the duration of each intervocalic interval to the duration of the next occurring intervocalic interval. The absolute difference, in milliseconds, between the members of each pair is added, and the resulting figure is divided by the number of pairs minus one. A normalised measure (nVoc) was used for vowels to take account of differences in speech rate as described above. This normalised measure is essentially the same as the raw calculation for intervocalic intervals except that the absolute difference between each pair is expressed as a proportion of the mean duration of that pair. These proportions are added and then the result is divided by the total number of pairs minus one. The resulting number is fractional so is multiplied by 100 for easier comparison with the non-normalised figure for intervocalic intervals. The equations for both the rInt PVI and nVoc PVI are given in the appendix, and a spreadsheet for calculating them can be found at http://www.phon.ox.ac.uk/~esther/.

For each participant 115 vocalic and 115 intervocalic intervals were measured (Grabe and Low (2002) used between 118 and 205 intervals for each language studied). These measurements were taken from around 60 seconds of speech in each case, which resulted in approximately fourteen hours of acoustic analysis. The acoustic analysis was undertaken by the first author using PRAAT 4.5.1.5 (Boersma & Weenink, 2006) with reference to the waveform and spectrogram, using standard procedures for measuring duration (Fischer-Jørgensen and Hutters, 1981; Peterson and Lehiste, 1960). The original PVI measure by Low *et al*. (2000) and Grabe and Low (2002) was applied to read speech that had been recorded in a speech laboratory. Therefore, because data for the current paper was conversation data recorded in non-laboratory situations, it was necessary to make some decisions about how best to analyse the recorded material. Firstly, because the recordings are of structured conversation, there are a small number of pauses (as shown in the transcripts of the conversations in the appendices). These pauses occur quite commonly at intonation phrase boundaries for both speakers, but are of a longer duration for the speaker with right hemisphere damage. These pauses were not included in the analysis. When a speaker paused, the relevant segment's end point was estimated as closely as possible. The duration of that consonant was then compared to the next occurring intervocalic interval after the pause. Likewise, there is an occasional dysfluency, where a speaker repeats a word or part of a word. These dysfluencies occur only rarely for each speaker. In most instances it was possible to divide even these dysfluencies into sequences of vowels and consonants whose durations are measured and treated in the same way as all the other durations. Also, because the signal to noise ratio (SNR) was lower than for laboratory speech (the SNR was variable over the course of the recordings, occasionally as low as 25 dB), the visual displays were sometimes difficult to interpret. In these cases more reliance was placed on listening in order to mark the interval boundaries.

Results

The results of the analysis show that the control participant had higher overall PVI scores for both vocalic and intervocalic measures than the speaker with RHD, as can be seen in Table 1. Low PVI values are associated with more syllable timed speech because successive vowel or consonant interval durations vary little. Therefore the lower PVI values suggest initially that the speaker with RHD spoke with more syllable-timed rhythm than the normal control. However, the PVI provides only a single nVoc and rInt figure for each stretch of speech analysed, and therefore cannot be used to conduct inferential statistics. In order to overcome this difficulty, the data was divided into five equal sets of 23 vocalic and 23 intervocalic intervals (following Grabe and Low (2002) who divided each participant's data into three sets). The sets were composed of consecutive intervals so that set one contained the first 23, set two the next 23 and so forth. PVI measures were then conducted separately for each set, as shown in Table 1 below. An independent samples two-tailed t-test showed that there was a significant difference between the normal control and the right hemisphere damaged patient for the rInt PVI ($t(8)=4.7$, $p<0.01$), but not for the nVoc PVI ($t(8)=1.7$, $p>0.05$).

Insert Table 1 about here

The control participant had high PVI values for both nVoc and rInt, which suggests an extremely stress-timed rhythm. Because this speaker is Australian, there is no other material available for comparison (although the collection of this data is planned by the current authors). However, it is enlightening to compare the results of the control participant to results available in the literature for British English. These results are shown in the Table 2. It is unfortunate that studies in the past have reported only the mean PVI score and not the range of values found across subjects. This leaves us with less detailed information with which to compare the current speakers, and means that z-scores cannot legitimately be computed.

However, if we look at the range and means of those means presented in previous studies, the nVoc PVI ranges from 57 to 78 (mean= 62), and the rInt PVI from 58 to 80 (mean 69). Again, the speaker with RHD shows a lower score for intervocalic intervals than has been reported for any other study, and the second lowest value for vocalic intervals.

Insert table 2 about here

Discussion

This study compared the rhythm of a speaker with RHD to that of a neurologically normal control using the pairwise variability index (PVI). The results show that the speaker with RHD spoke with a more syllable-timed rhythm than the control, and that this result is significant for the durations of intervocalic intervals.

Relationship of control participant's results to measures of British English

In general, it seems that the Australian English of the control participant has a similar rhythm to British English. Halliday (1985) classified British and Australian speech as being more rhythmically regular than American or Canadian speech, and phonologically Australian English is much closer to Received Pronunciation (RP) than many other varieties of English (Wells, 1982). These similarities would, of course, be expected given the pattern of immigration from England to Australia in the late 1700s although there are of course many phonetic differences between Australian and British English which have developed over the intervening time.

One particular difference between the two varieties occurs in intonation. Since the 1970s (Horvath, 1985), many speakers of Australian English have begun to produce statements that end in a high rising nuclear tone (Fletcher and Harrington, 2001). By contrast, RP statements tend to end in a falling tone (although the Australian pattern is now used by many younger speakers of British English). This intonational difference between the two varieties might have suggested there would also be a rhythmical difference as both intonation and rhythm are prosodic features, and we know that both can vary between dialects of the same language. Furthermore many varieties of English are more syllable-timed than British English (Crystal, 1996).

However, the rhythm of the control participant, who is a speaker of Australian English, appears to be highly stress-timed like that of British English. This is likely due to the shared phonological characteristics of the two languages. For example, the details of vowel reduction and onset and coda complexity are very similar across the two varieties, unlike for some newer World Englishes. We await the results from further speakers to see if this result can be generalised to Australian English as a whole.

Relationship of RHD participant to the control participant and to other PVI measures

For the RHD speaker we can see that there is a more syllable-timed rhythm than that found for the control participant or speakers of British English. This more syllable-timed rhythm was perhaps, therefore, the underlying reason for the speech pathologist's perception of unnatural prosody in the speech of this client. The results indicate that the significant difference between the two speakers comes from the more regular intervocalic intervals used by the participant with RHD. Although the RHD participant also appears to use more regular vocalic intervals, there is no significant difference when compared to the normal control participant. This may suggest that the patient with RHD is avoiding complex consonant clusters (as has been found in speakers with apraxia of speech by Edmonds and Marquardt, 2004). However, the large, albeit non significant, differences found for vocalic intervals suggest that other factors are at work, and further explorations with more controlled data are needed before a firm conclusion can be drawn.

Another important issue is the possible description of the RHD speaker's rhythm as 'syllable-timed'. This description is probably best avoided for two reasons. Firstly, as discussed above, rhythm is now generally believed to be a gradient phenomenon rather than the strict dichotomy between stress- and syllable-timed languages (and varieties) proposed by Abercrombie (1967). Indeed, in their classification of different languages, Grabe and Low (2002) point out that, although the nVoc PVI perhaps gives a categorical split, the rInt PVI gives a gradient distribution. The second difficulty comes when comparing the RHD speaker's PVI values to those for other languages. The rInt PVI of 52 is quite similar to those Grabe and Low found for the classically syllable-timed languages of French (50) and Spanish (58). However, the nVoc PVI of 61 can certainly not be described as syllable-timed, as French and Spanish have values of 44 and 30 respectively. Rather than describing the rhythm of the RHD participant as syllable-timed, it seems most sensible to say that this speaker produces speech that is less strongly stress-timed than that of the control participant, or the British English speakers reported in the literature.

It is also interesting to consider how this finding relates to other findings of dysprosody in speakers with RHD. As discussed above, the evidence supporting lateralisation of prosody to the right hemisphere is equivocal. This is especially true for linguistic prosody, but there is perhaps some weak evidence for lateralisation of affective prosody to the right hemisphere. Nevertheless the general consensus of opinion is that some elements of, or cues to, prosody involve right hemisphere processing. As mentioned above, rhythm cannot be classified as either a linguistic or affective aspect of prosody. It is, in fact, more akin to the phonological inventory of a particular language and a deficit at this level suggests a deep-seated, albeit subtle impairment. The evidence presented here suggests that rhythm production may be processed by the right hemisphere, at least for the single RHD speaker studied, although further studies, including those considering LHD patients are necessary to further strengthen this conclusion.

Relationship of RHD speaker's rhythm to that found in other neurological conditions

It is interesting to note that the speech of individuals with Foreign Accent Syndrome (FAS) and ataxic dysarthria have both been described as more syllable-timed than that of normal controls. Speakers with Foreign Accent Syndrome appear to speak with a foreign accent after a stroke. In the majority of cases damage is to the left hemisphere, and in these cases, prosody is the feature of speech most usually described as contributing towards the perceived foreign accent (Dankovičová, Gurd, Marshall, MacMahon, Stuart-

Smith, Coleman, and Slater, 2001, p.197). In particular, rhythm is often described as being more syllable-timed when English speakers develop FAS. Dankovičová *et al*. summarise a number of features which may lead to the impression of syllable timing. These features include: more equal syllable durations, non reduction of unstressed vowels, insertion of vowels, misplacement of lexical stress and reduced intensity of stressed syllables. Interestingly, however, when Dankovičová *et al*. investigated the speech of a patient with FAS arising from <u>RHD</u> they found little prosodic disturbance, a point that will be returned to shortly.

Speakers with ataxic dysarthria have also been described as having a more syllable-timed rhythm (although the term 'scanning speech' is often used following Charcot, 1879) on the basis of impressionistic analyses. Using an early forerunner of the PVI, Ackerman and Hertrich (1994), and Kent, Kent, Rosenbek, Vorperian, and Weismer, (1997) found little evidence of syllable timing for this population. However, the metric used appears to be overly sensitive to the durations of individual syllables (Kent and Kim, 2003, see p 440). By contrast Stuntebeck (2002, as reported in Kent and Kim, 2003) used the PVI and found lower values for a group of speakers with ataxic dysarthria than for a similar group of healthy control participants, thus supporting the perceptual impressions of syllable timing.

It is somewhat puzzling why three different neurological conditions should all lead to impairment in rhythm. Whilst the focus in this study is on RHD, the cases of FAS have usually involved LHD, and ataxic dysarthria is usually attributed to damage of the cerebellum and cerebellar pathways. Furthermore the case of FAS in a person with RHD reported by Dankovičová *et al*. (2001) showed little prosodic disturbance of any kind. It is possible that these different findings demonstrate that rhythm cannot be strictly lateralised to one hemisphere, or, as many different factors may lead to syllable-timing, that these different factors are differently lateralised.

It is also noteworthy that the same type of disturbance, that is more syllable-timed rhythm, is found in each case. This may simply be because English is so strongly stress-timed that any disruption tends in the opposite direction. It would, therefore, be interesting to examine these neurological conditions in speakers of strongly syllable-timed languages to see if their rhythm becomes more stress-timed. The answers to these questions are beyond the scope of this paper and await further work to apply the PVI to different populations, and to clients with different native languages.

Finally, it is possible that, like the RHD participant studied here, speakers with ataxic dysarthria and FAS also have a 'less stress-timed' rather than a syllable timed rhythm per se. However, further evidence is needed in the form of PVI measures compared to those of normal participants in several languages.

Issues in analysis

The results of the current study suggest a number of conclusions about prosody production in speakers with RHD. However, they must be treated with sufficient caution for a number of reasons. Firstly, only one speaker and one control participant were analysed, and there is always the possibility that these speakers are not representative of their respective populations. However, the control participant's results fit well with those found for British English, and the speech of the speaker with RHD presents similarly to other brain damaged populations that have been associated with syllable-timing.

Secondly, the nature of the speech task is somewhat uncontrolled which is rather different to previous applications of the PVI which have been conducted on carefully controlled speech. Although the speakers in the present study are asked the same questions they necessarily give different answers, meaning that the data analysed is not lexically identical. However, in previous studies applying the PVI to different languages (such as Grabe and Low, 2002) the data was also, necessarily, lexically different for each speaker.

Related to the nature of the task is the nature of the recording environment. The original PVI measures were applied to recordings made in optimal conditions, whereas the results reported in the current experiment were made in a clinic and a participant's home. This means that it was sometimes more difficult to use a visual signal to measure durations, and consequently more reliance was placed on listening. The nature of the recording environment and the limitations of the task are necessary consequences of working with clinical populations. However, the authors contend that the results presented in this paper can be treated with confidence as the control participant's measures were so similar to those previously described for other varieties of English.

Conclusion

The results presented in this paper indicate that there is a deficit in the rhythm produced by a speaker with RHD, which leads to a less strongly stress-timed rhythm than that of a normal control in respect of intervocalic intervals. This may suggest that some aspects of speech prosody are right lateralised for this speaker. The authors of this paper are currently undertaking a study with more subjects, and with a more controlled task and recording environment in order to ascertain how far this finding can be generalised.

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Appendix 1

Sample of speech from normal control participant

Something where you’re happy rather than say sad oh when the Dockers won (0.8) last Saturday week (0.6) the Dockers beat Essendon now you I'm sure you do know that Essendon's been one of the erm foremost teams in football and won the premiership (0.4) two years ago and's been one of the leading teams for (0.5) several years (0.6) and to beat Essendon's a feather in any team's cap let alone a team like the Dockers (0.3) and so Essendon came over here (0.4) the Dockers would have been given absolutely no chance whatever of winning

(figures in parenthesis show pauses in seconds)

Appendix 2

Sample of speech from participant with right hemisphere damage

Well we were (0.9) we were a camp (0.9) on the Broome side of the Fitzroy river (0.3)on Newman Station, (3.0) And then there was people on the on the Derby side (0.7) that we knew they'd happen to be apprentice police (2.9) so they hopped in our boat with us and did fi- and went fishing with us (0.7) They had their own boat (0.6) 'cause we went up beyondd the river in the dark (1.3) side by side and an all a sudden they went missing (1.1) we didn't know where we where they went (0.67) so we turned around another corner up on the fork of a dead tree that was sticking up out of the water

(figures in parenthesis show pauses in seconds)

Appendix 1

1. $r\,PVI = \left[\sum_{k=1}^{m-1} \left| d_k - d_{k+1} \right| / (m-1) \right]$

2. $nPVI = 100 \times \left[\sum_{k=1}^{m-1} \left| \frac{d_k - d_{k+1}}{(d_k + d_{k+1})/2} \right| / (m-1) \right]$

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Tables and figures

Figure 1 An example of how vocalic (V) and intervocalic (I) intervals were measured. Intervals include all successive vowels or consonants, even if these segments straddle a word boundary.

/	ð	i	ɛ	l	ə	f	ə	n	t	r	æ	n	/
	I1	V1		I2	V2	I3	V3	I4			V4	I5	

Table 1 nVoc PVI and rInt PVI overall and for each section, for each participant.

Participant		nVoc PVI	rInt PVI
RHD participant	**Overall**	**61**	**52**
	Section 1	54	46
	Section 2	69	57
	Section 3	59	47
	Section 4	76	47
	Section 5	57	61
Control participant	**Overall**	**72**	**83**
	Section 1	60	96
	Section 2	74	100
	Section 3	67	69
	Section 4	88	90
	Section 5	82	71

Table 2 PVI results for British English from previous studies, compared to those of the control and RHD participants.

Previous studies do not present PVI values for individual participants, so the numbers in the table represent the means presented in each study. The values from Low *et al*. (2000) are approximate as they appear only in a bar chart in the original publication.

Study	**Number of speakers**	**Average nVoc PVI**	**Average rInt PVI**
Low *et al*. (2000)	10	≈78	≈75
Grabe and Low (2002)	1	57	64
Grabe *et al*. (1999) (as reported in Whitworth 2002)	8	69	80
Whitworth (2002)	3	69	58
White and Mattys (in press)	3	73	70
Control Participant	*1*	*72*	*83*
RHD participant	*1*	*61*	*52*