SPEECH AND LANGUAGE

Production and perception of word stress in children and adolescents with Down syndrome

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This article reviews the importance of word stress for typical language acquisition and presents evidence that in certain developmental language disorders, processing of word stress is disrupted. Two novel experiments were carried out testing the production and perception of word stress in a group of 16 children and adolescents with Down syndrome (ages 11-20) matched on receptive vocabulary level to 12 typically developing children (ages 4.06-7). The results indicated processing difficulties in both the production and perception of more difficult and later acquired stress patterns as well as weak initial syllables at the beginnings of words. The impact of these difficulties on language acquisition processes is discussed and future avenues for research are sketched.

Introduction

Word stress is involved in language processing in adults and children, and is instrumental to the language acquisition processes of typically developing children. Over the past decades, there has also been mounting evidence that stress patterns may not be processed as efficiently in different types of language disorders[1-6] and that this may significantly contribute to difficulties with language. The language problems of children with Down syndrome are increasingly viewed as a language disorder rather than as the mere consequence of having Down syndrome: not only does the language impairment exceed the level predicted by non-linguistic cognitive functioning, but a series of studies have found highly similar patterns of language breakdown between children with Down syndrome and children with Specific Language Impairment (henceforth SLI), who, in spite of unimpaired non-linguistic cognition and no frank neurological disorder, have a language disorder[7,8,9]. Indeed Paoloni-Giacobino, Lemieux, Lemyre and Lespinasse present the case of a teenage girl with trisomy 21 mosaicism who has age-appropriate cognition but presents a case of severe SLI[10]. The authors propose that a language impairment is part of the phenotype of Down syndrome, rather than being caused primarily by the learning difficulty associated with the syndrome. In light of this research and the importance of word stress in typical acquisition, as well as its possible involvement in language disorders, the question of how well word stress is processed by children with Down syndrome becomes a pressing issue.

Human language is characterised by the rhythmic alternation of more and less prominent units, and phonologists and psycholinguists have long argued that this pattern of peaks and troughs is necessary for efficient language processing[11]. Word stress has been shown to be particularly important. The term 'word stress' refers to prominence patterns of syllables within a word; for example in '**ci**ty' the first syllable (in bold typeface) is the most prominent, whereas in 'set**tee**' the second syllable is strong and therefore carries stress. In English, the strong-weak pattern is the most prevalent, although in other languages different patterns are preferred. For example in Spanish, the weak-strong pattern is more common and in French, words have stress on the last syllable (this discussion has simplified a highly complex linguistic phenomenon, and the reader is referred to Hayes[12] for a comprehensive treatment of stress systems).

Word stress has been shown to play an important role in language processing by adults. Psycholinguistic experiments have shown that English-speaking adults use the most common strong-weak stress pattern to extract words from fluent speech in difficult listening conditions[13,14,15]. A similar reliance on word stress has also been shown for typically developing children, as they become attuned in to the stress

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patterns of their native language at a very early age. Weber, Hahne, Friedrich and Friederici[16] demonstrated that German infants as young as five months were sensitive to the predominant strong-weak stress pattern of their native language. Similarly, English-learning 9 month olds prefer to listen to word lists containing the more prevalent strong-weak stress pattern than to lists of weak-strong words. This preference is maintained even when the words have been low-pass filtered so that only the stress pattern remains discernible, showing that this aspect of the word is most salient to infants at this age[17]. Importantly, infants were shown to use this preference for strong-weak stress patterns to detect words in fluent speech and to help them develop their lexicon[18,19].

Word stress is not only crucially important in the processing of language, it also drives the development of speech: researchers such as Demuth[20,21], Kehoe[22,23,24] and Fikkert[25,26] have shown that the earliest utterances of young children are organised around the most prevalent native stress patterns and that children use this to gradually build up from simple forms to more complex phonological structures. For English, where the preferred stress pattern is strong-weak, weak syllables such as the first syllable of 'ba**na**na' are initially omitted. This word provides a good illustration of how children progress in their prosodic development: the first attempts will consist of simple consonant-vowel sequences such as 'na' or 'ba'. Children then move to include more of the word, and will say things like '**ba**na' or '**na**na'. Notice that both forms begin with a strong syllable, but that this need not correspond to the one in the target word. This shows that children do perceive the weak syllable, but find it difficult to incorporate it into their output. Indeed, when children start to attempt the full length of weak-initial words, they will often use reduplication rather than producing a weak syllable at the beginning of the word: so 'ba**na**na' becomes '**ba**ba**na**na' (this example is simplified from Demuth and the reader is referred to this for a more detailed discussion[20]).

The reduplication and omission of syllables in difficult stress structures are not the only means employed by children to simplify structures. More rarely children also alter the stress pattern to make it conform to a simpler form: for 'ba**na**na', this means shifting the stress to the first syllable, so that the word becomes '**ba**nana'. Another strategy is to accent each syllable equally, also described as 'level stress'. In these examples it is simply not possible to determine where the main prominence is. Both Kehoe[22,23,24] and Fikkert[27] have documented transitional phases when stress errors (either changes to stress structure or level stress) are frequent in children's speech. Nevertheless, these are short phases and children's preferred strategy for dealing with difficult structures is omission or reduplication.

It would be misguided to view the difficulties with weak-initial syllables as a simple articulatory constraint, since structures which do not start with a weak syllable but represent exceptions to other aspects of English stress patterns also cause difficulties. One such structure is known as 'compound stress'. In English, words can have more than one stressed syllable, but one of the stressed syllables will be more prominent (also known as main stress). In most cases, this will be on the second syllable from the right, as in '**se**mo**li**na' or '**Cin**de**re**lla'. In addition to this most prominent syllable, both words also have a second stressed syllable at the beginning of the word, although this is less prominent than the main stress on the second syllable from the left. This type of stress pattern is the most frequent in items with more than three syllables, and it is therefore viewed as the default structure. In contrast, compound structures carry main stress on the first syllable, as in '**ca**ter**pi**llar', where the main prominence is on the first syllable and the second prominence is on 'pi'. Notice that both types of structures start with a strong syllable and that it is merely the location of the main prominence which differs, but nevertheless the compound pattern causes great difficulty in acquisition, whereas the default structure is acquired much earlier (for a more detailed explanation of this phenomenon, see Kehoe[22,23] and Fikkert[27]).

Data from both Kehoe and Fikkert suggest that by the age of four, children have largely acquired their native stress system (with the exception of rare structures found in Latinate forms). However, in some children with developmental language disorders, word stress does not seem to be processed as adequately. Within the context of a large-scale longitudinal study, Weber, Hahne, Friedrich and Friederici[6] retrospectively examined the ERP responses to changes in stress pattern by five month old German infants. The infants were divided into two groups: infants whose language development at 12 and 24 months was within typical norms, and a small group of infants who at both 12 and 24 months had had very low word production scores on a standardised assessment for communicative development, and who were therefore classified as being 'at risk' for SLI according to a German equivalent[28] to the MacArthur CDI[29]. It was found that when compared to the typically developing group, the infants later classified as at risk for SLI had significantly reduced ERP responses to changes in stress pattern already at five months. This was thought to indicate less effective processing of word stress by infants in this group. The authors point out that if word stress is not processed as adequately, it would explain the slow start to language, since stress is the primary cue used by infants to recognise words in fluent speech.

The development of stress patterns in the spoken language of children with language disorders is also delayed: complex stress patterns emerge later and development is slower. Bortolini and Leonard showed that children with SLI omitted word-initial weak syllables much more frequently than typically developing children matched on mean length of utterance[30]. Aguilar-Mediavilla, Sanz-Torrent and Serra-Raventos[31] suggested that this constitutes a plateau in the development of stress structures when other aspects of language have continued to develop. De Bree et al. found that children at risk for dyslexia were significantly less able to repeat more difficult and later-acquired stress patterns than age-matches who did not have a familial risk for dyslexia[32].

Although stress errors such as changes to stress patterns or level stress are less often reported in typical acquisition, some authors have described this in language disorders: Fikkert and Penner describe two cases of young children with SLI who produce an unusually high number of level stress forms[1]. The authors explain this in terms of a stagnation of development, where children have acquired one aspect of their phonology, for example that words can have both primary and secondary stress, but are not able to implement this difference yet. They therefore resort to rendering the word with two equal stresses. Fikkert and Penner propose that an over-abundance of stress errors is characteristic of a language disorder. This idea is echoed by Shriberg et al., who discuss a sub-group of children with suspected developmental Apraxia of speech, whose speech is characterised by stress errors[4,5]. The authors explore the idea that this could represent a distinct phenotype of linguistic impairment. However, it is presently not clear whether a high incidence of stress errors truly represents a distinct type of language impairment from children who mostly use omission to simplify complex forms.

In contrast to the literature on other types of developmental language disorders, little is known about whether the difficulties with language seen in Down syndrome also involve problems with the acquisition and processing of word stress. Research on phonological development in children with Down syndrome has shown that this is slowed down beyond the level predicted by non-linguistic cognitive functioning and is characterised by greater inconsistency than that of mental age matches[33,34,35]. It should be pointed out though that little is known about how word stress contributes to this pattern of impairment. A few studies of language in Down syndrome have included some aspect of prosody (i.e. intonation and rhythmic aspects of language)[36,37], but none of them have assessed word stress directly. In fact, more studies of prosody are needed, as detailed linguistic-phonetic analyses of the speech of individuals with Down syndrome have shown that speech intelligibility and error patterns in this population are strongly affected by prosodic and rhythmic phenomena[38,39,40]. Furthermore, given the similarities between the language profiles of children with SLI and children with Down syndrome, an exploration of word stress processing is timely and addresses an under-researched topic in this population. Therefore, it was decided to carry out two experiments assessing the processing of word stress in this population: the first experiment examined production whilst the second assessed perception.

Experiment 1: production of stress patterns

In order to investigate the production of stress patterns in children with Down syndrome, a nonsense word repetition task (NWREP) was used in which participants were asked to repeat nonsense words, i.e. words which correspond to the phonology of English but have no lexical meaning. Although this methodology is traditionally used to investigate phonological short-term memory[41,42], it has also been used successfully to investigate the impact of linguistic factors on language processing[43,44]. The majority of psycholinguistic models of speech processing assume that phonological and semantic/lexical aspects of words are accessed at separate stages in word production and perception, and that these may therefore also be separately impaired in production or perception[45,46,47]. Because nonsense words have no semantic or lexical meaning, they are thought to tap only phonological processing. This avoids potentially confounding factors such as lexical or frequency effects. A second reason for using nonsense words is that the impact of word stress can be directly assessed by comparing nonsense words which contain the same phonemes but have a different stress structure.

The task examined the impact of stress phenomena which have been well researched in the literature on typical acquisition: the first variable therefore concerns the processing of words starting with weak-initial syllables compared to those starting with a strong syllable. As short-term memory has a strong impact on the ability to repeat nonsense words[48], the second experimental variable is the number of syllables in the nonsense words, i.e. there are nonsense words with two, three and four syllables. The third variable relates to the four-syllable nonsense words, where a distinction was implemented between the default stress pattern (as in 'semo**li**na') and compound stress (e.g. '**ca**terpillar'). The default pattern is represented by items which have the main stress on the second syllable from the right (swSw), while the words with compound stress carry main prominence on the first syllable (Swsw).

By the age of four years, word stress is assumed to be acquired[25,49], and the inclusion criterion for participants was therefore set at an age equivalent score of no less than four years for receptive vocabulary. Receptive vocabulary size was preferred over productive vocabulary because the former is known to be higher than the latter in children with Down syndrome[50] and therefore represents a more adequate reflection of competence.

Predictions

In line with results of word stress production in typically developing children and children with a developmental language impairment, it can be expected that participants with Down syndrome display more problems with the repetition of words with a weak-strong stress pattern than the strong-weak stress pattern which is predominant in English. Additionally, on items of four syllables participants with Down syndrome are predicted to have greater difficulties with compound structures, as acquisition studies suggest that these appear later[21,23,51]. Because children with Down syndrome have a well-documented short-term memory impairment, performance is predicted to drop with increasing numbers of syllables[52].

Method

In this production task participants were asked to repeat 32 nonsense words which were designed to experimentally control for three variables: word stress (weak-initial versus strong-initial forms), word length (two, three and four syllables) and on items of four syllables there was an additional variable examining the impact of compound stress (Swsw) compared to the default stress pattern (swSw).

Number of syllables	Simple stress pattern	Complex stress pattern
1	[ˈdɑː] (car)	
2	[ˈdɑːpə] (**fa**ther)	[dəˈpɑː] (set**tee**)
3	[ˈfidəpə] (**ce**lery)	[fɪˈdʌpə] (ba**na**na)
4	[fɪdəˈpʌlə] (semo**li**na)	[fɪˈdʌpələ] (ma**jo**rity) [ˈfidəpʌlə] (**ca**terpillar)

Table 1 | **Examples of stimuli and their real word equivalents**

Key to phonetic symbols:

ɑː = the vowel in 'father'

ʌ = the vowel in 'cut'

ə = the first vowel of 'banana'

ɪ = the vowel in 'bit'

ʊ = the vowel in 'book'

ʃ = the first consonant in 'ship'

ˈ = indicates that the following syllable carries main stress

Examples of the nonsense words in each of the experimental conditions are given in TABLE 1. There were four items with different phonemes for each of the eight conditions, i.e. 4x8 = 32. As phonemes can have an impact on the accuracy of stress production[49], they were kept the same in items with the same number of syllables but different stress patterns (e.g. [fɪdəˈpʌlə] and [ˈfidəpʌlə])[a].

One syllable items only served as fillers and were not included in any analyses.

Stimulus preparation

The nonsense words were read by a female native speaker of Standard Southern British English. The nonsense words were presented to the speaker in blocks with the same length and stress conditions grouped together to achieve greater consistency in the speaker's pronunciation of the words. Furthermore, each block was preceded by examples of real words containing the same stress pattern. The speaker was instructed to maintain the same volume, pitch and intonation contour on all nonsense words. The speaker was also made aware of the phenomenon of list intonation, and took care to avoid it. The list with all the nonsense words was read five times by the speaker.

The speaker's deliveries of the nonsense words

[a] Sometimes a phoneme had to be altered between two stress structures, as one of the tokens would otherwise have contained a real word. Moreover, there is a difference in the vowel quality between stressed and unstressed syllables, but this is part of the phonology of English stress[61] and could therefore not be avoided.

[b] We are most grateful to Maggie Vance, Stuart Rosen and Mike Coleman at University College London for allowing us to use SIPC.

	N	Minimum	Maximum	Mean	Std. Deviation
Down syndrome	15	4.04	7.07	5.44	0.91
Typically developing	12	5.01	7.05	5.80	0.85

Table 2 | **Descriptive statistics for BPVS II vocabulary age equivalent scores for both groups**

were recorded onto a standard DAT tape using a Tascam DA-P1 DAT recorder and a Shure SM57 dynamic microphone in a sound-insulated room with reduced reverberation at City University. The whole recording was then digitized at 16 kHz/16 bits onto a Toshiba Tecra A2 laptop PC computer. The most natural realisation of each nonsense word was selected using the sound editing software Cool Edit 2000 and incorporated into dedicated non-word repetition task software SIPC©[53]b.

Participants

Two groups of participants took part in the experiment: a group of 16 children and adolescents with Down syndrome (six females and ten males; ages 11-20) and a group of 12 typically developing children (ages 4.06-7.00). The groups were individually matched on sex and receptive vocabulary level using the age-equivalent scores of the BPVS II[54], a standardised measure of receptive vocabulary size. For vocabulary level, the inclusion criterion an age equivalent score of at least four years of age.

Participants were also screened for hearing problems using pure tone audiometry. Hearing thresholds were obtained for frequencies 500, 1000, 2000 and 4000 khz and averages were calculated for each ear. The inclusion criterion was set at a composite threshold of no higher than 35 dB HL in the better ear (in fact all the participants had thresholds below 25 dB HL except one whose thresholds lay closer to 35 dB HL).

Initially, 32 participants with Down syndrome were recruited, but only 16 passed the inclusion criteria. For the control group, 21 typically developing children were recruited and 12 of those were suitable vocabulary matches.

Procedure

The participants were seen individually in a quiet room at their school. Some of the participants with Down syndrome were visited in their homes. The group with Down syndrome was tested before the control group. All participants started by completing the BPVS II and were subsequently tested via pure tone audiometry [c]. If participants were not too tired, the nonsense word repetition task was carried out straight away. Otherwise they returned to their classroom and completed this task in the next session. Every session lasted between 20-30 minutes.

In the instructions to the NWREP, participants were told that they were going to play a game for which they had to try to repeat the 'funny words' which the computer would say to them. Participants were asked to listen to each stimulus and repeat it right away. There was a short practice phase during which participants were encouraged to adjust the volume to a comfortable level. After each repetition, they were praised and encouraged. Half of the participants heard tokens 1-32, while the other half heard tokens 16-32 first followed by 1-15. The presentation sequence of the tokens was semi-randomised so that two stimuli representing the same experimental conditions would never be adjacent.

The stimuli were presented via a Toshiba Tecra A2 laptop PCs, using the non-word repetition task software in SIPC©. Participants listened to the stimuli over Sony dynamic stereo headphones (DMR – V300). A 24-bit Sound Blaster Audigy 2NX external sound card was used for playing the stimuli. Participants' repetitions were digitally recorded at 44 khz and 16 bits onto the same laptop using a Sony F-V420 unidirectional microphone and creative Mediasource player, the software of the external soundcard.

Results

The productions of all the participants were perceptually assessed by two phonetically experienced judges [d] who were asked to score each of the participants' productions as correct or incorrect. It became clear that inclusion of phonemic pronunciation errors would bring the experimental group to floor level. Phonemic errors were therefore disregarded and repetitions were scored as correct if they displayed the correct target stress pattern and the correct number of syllables. In addition, the difference between primary and secondary stress was hardly ever perceivable in the four syllable word realisations of the participants with Down syndrome. Scoring

[c] One participant did not agree to take part in the audiometry procedure, but parental reports indicated that a recent audiological examination had shown his hearing to be within the normal range.

[d] We would like to thank Dr Barrett-Jones for her help with scoring the data set and Ms Bannister for scoring the data for the reliability test.

this as an error would bring the participants with Down syndrome again at floor. As a result, the criterion of primary and secondary stress had to be dropped as well, and repetitions were scored as correct as long as they started with a stressed or unstressed syllable like the target.

In their assessment of the nonsense word realisations, judges had to reach agreement, but if this could not be achieved for a particular nonsense word, it was scored as incorrect. In order to assess inter-rater reliability, a random selection of 15% of the data was re-examined by a third phonetically competent rater. The error scores of the first two raters and the third rater were compared using Cohen's Kappa and a good correlation was obtained (κ= .84).

Besides judgements on the correctness of participants' responses, the raters also marked the kind of errors that were made: changes in the number of syllables were marked as syllable errors, while alternations in the stress patterns were marked as stress errors. To assess inter-rater reliability, the error types of 15% of the data were again compared with the judgements of the third rater using a Cohens Kappa, which found satisfactory agreement (κ= .74)

The correctness judgements and error analyses were analysed statistically using SPSS 12.0.1 for windows. The typically developing children only made a total of six errors and hence were at ceiling; this would have been the case even if phonemic errors had been taken into account. This group of speakers was therefore excluded from further analyses.

The judgements for the Down syndrome speakers were analysed by means of a two-factor ANOVA with the factors word length (three levels: two, three and four syllables) and stress pattern (two levels: weak initial and strong initial) in order to examine whether differences could be found in their production of stress patterns. In this analysis the four syllable items were only represented by the default pattern (swSw) with main stress on the second syllable from the right. Both main effects were significant, length $F(2,30) = 22.68$; $p < 0.001$ and stress $F(1,15) = 8.86$; $p < 0.01$ as well as their interaction $F(2,30) = 3.95$; $p < 0.05$. FIGURE 1 summarises the performance of the Down syndrome group on items of different lengths in weak-initial and strong-initial words.

From FIGURE 1, it can be seen that increasing word length has affected repetition ability in both stress conditions and that participants did worse on the weak-initial forms in the four-syllable nonsense words. A related samples t-test

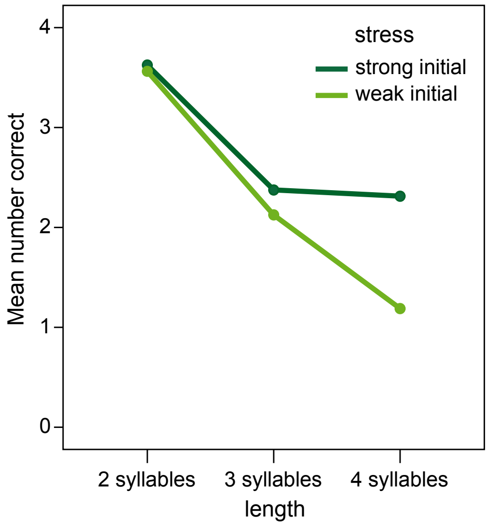

Figure 1 | **Performance of the Down syndrome group on weak-initial and strong-initial items, using the neutral swSw pattern for the 4 syllable items**

revealed that this difference was statistically significant $t(15) = 5.08$, $p < 0\ .001$.

In order to establish the possible role of the location of the primary stress position in four syllable items, the same ANOVA was carried out, this time using the stimuli with a compound stress pattern (Swsw). For the main effects, only length was significant $F(2,30) = 27.71$; $p < 0.001$, whereas stress was not $F(1,15) = 3.06$; $p > 0.05$, nor was there any significant interaction $F(2,30) = 0{,}96$; $p > 0.05$ between the main effects. FIGURE 2 shows that speakers' performance decreases with increasing word length. This indicates that weak-initial stress structures and compound stress are equally difficult for the speakers with Down syndrome.

Finally, the relationship between hearing and performance on the NWREP was investigated by entering the average for the better ear and the overall score of the 15 participants with Down syndrome [e] into a Spearman's Rank Correlation. This analysis indicates that the two factors were not correlated ($R(15) = 0\ .156$, $p > 0.05$).

Discussion

In order to investigate the repetition success of nonsense words varying in length and stress pattern, a nonsense word repetition task was carried out in children and adolescents with Down syndrome. The results of this experiment revealed three important effects: As word length increases, repetition success goes down significantly. Averaged over the two stress conditions, repetition success was 90%, 56% and 44% for the

[e] One of the participants refused to wear the headphones of the audiometer, therefore his data could not be entered in the correlational analysis. Parents' reports state that for the past years, his hearing has been found to be at normal levels during visits to Audiology clinics.

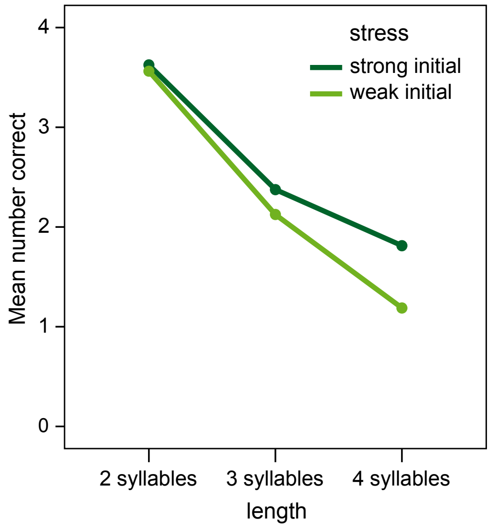

Figure 2 | **Performance of the Down syndrome group on weak-initial and strong-initial items, using the compound stress pattern Swsw 4 syllable items**

2, 3 and 4 syllable words respectively. There was no significant difference in the repetition success of the different stress patterns in the nonsense words with two and three syllables. However, repetition success of the four-syllable nonsense words was significantly related to the stress pattern involved. The four-syllable nonsense words with the default stress pattern (FIGURE 1) showed significantly fewer production errors if the word started with a strong initial syllable; words with weak initial syllables were less successfully produced. In the four-syllable nonsense words with compound stress pattern (FIGURE 2), there was a slight difference in repetition success between words starting with strong and weak initial syllables in that the words with weak initial syllables were produced less successfully. The difference, however, did not reach statistical significance.

There are two possible interpretations of these observations:

Repetition success is dependent on the stress pattern involved and as such the repetition ability of the group with Down syndrome is sensitive to word stress, as it deteriorates to a different extent with increasing word length depending on the stress structure involved. Since all the participants have a receptive vocabulary of at least four years, stress structures should have been fully acquired. This indicates that stress patterns are not processed equally efficiently. Therefore it can be suggested that the phonological system of the participants with Down syndrome seems to operate below the level adequate for their receptive vocabulary. Specifically, children and adolescents with Down syndrome have disproportionate difficulties with weak-initial syllables and compound stress structures on the four-syllable items. In these items, memory load may have magnified the impact of prosodic complexity, indicating that weak-initial and compound stress structures are not processed adequately in output phonology. These forms are notoriously difficult to master for children and are acquired late in prosodic development[21-24,44,55]. A similar effect of weak-initial syllables has also been reported by researchers working with SLI children[31,43].

The lack of difference between weak-initial and strong-initial items on the shorter two and three syllable words indicates that participants with Down syndrome are nevertheless essentially able to produce weak-initial forms, which suggests that difficulties with such items cannot be attributed solely to articulatory constraints. This is supported by the effect of main stress in the four-syllable items. Both types begin with a stressed syllable, but they differ in the location of main word stress. Although main and secondary stress could often not be determined in the utterances of the group with Down syndrome, the role of main stress is nevertheless reflected by the results of the NWREP. Only items with the default stress pattern were significantly better than weak-initial items, whereas items with compound stress did not differ from these, indicating that this stress structure is more difficult to process. Therefore, strong-initial items are not intrinsically easier to produce, but the whole structure impacts on performance. This result is in keeping with the literature on stress acquisition[23,49]. Therefore the performance of the group with Down syndrome is not random but does adhere to developmental linguistic principles, i.e. weak-initial and compound forms have not been successfully acquired yet.

Forty-eight percent of the errors by the experimental group had to do with stress (this figure comprises changes to stress patterns and ambiguous stress) [f]. Because the control group was at ceiling, it is not possible to decide whether this figure is unusually high. It is problematic to compare these figures to acquisition studies, because the investigated metrical structures and word types (i.e. real words or nonsense words) differ. Bearing this in mind, the figure does seem high, since in Kehoe's study with typically developing children between the ages of 18-36 months, comparable percentages of stress errors were only evident on complex and rare stress patterns[23].

[f] One possibility is that this figure was artificially inflated by having two raters: when these did not agree on the stress structure of an item, it was classified as 'stress uncodable'. This explanation is however rendered doubtful by the fact that both error scores and error types obtained good agreement rates with a third rater.

An alternative interpretation is that the obtained differences in repetition success are the result of a generalised impairment of auditory discrimination or short term memory. Suggestive of this is the fact that participants' repetition success is already significantly worse in the three-syllable items as compared to the two-syllable items, without any differences between words with different metrical structures. A counter argument to this is the fact that such generalised impairment of auditory discrimination should not lead to a differential repetition success in the four-syllable nonsense words depending on the metrical pattern involved. It can, however, not be entirely excluded on the basis of the results obtained in this experiment. In order to investigate the possible role of auditory discrimination or short term memory, it was decided to carry out a discrimination experiment, which will be reported in the next section.

Experiment 2 – perception of stress patterns and weak syllables

Having examined the production of stress patterns by Down syndrome speakers in a nonsense word repetition task, a perception experiment was carried out which focused on those aspects of the NWREP which caused particular difficulties, i.e. stress and weak initial syllables. In order to control for the possibility that errors might just be due to a general impairment in auditory perception or short term memory, an additional variable was included which participants should be able to discriminate on the basis of research into typical language acquisition. More specifically, weak syllables at the end of words have been shown to be preserved in typical language acquisition[24,49]. Participants should therefore be able to process weak syllables in word-final positions adequately.

As in the first experiment, each of the three variables, weak-initial syllables, word stress and weak final syllables are tested in words of three different lengths: two, three and four syllables. Difficulties with individual variables should be more apparent in longer items. Perception of the variables was investigated in an XAB discrimination task.

Predictions

If the participants with Down syndrome have a general problem with auditory discrimination, either due to auditory processing difficulties or short-term memory, their discrimination should be equally affected by all three variables and performance should deteriorate uniformly with increasing word length. If however performance is influenced by linguistic factors, only weak initial syllables and stress should be affected.

Method

In an XAB discrimination task, participants have to identify which one of two stimuli (A and B) match the first (X). The computer programme SIPC[53] presents the stimuli in the form of three space ships containing aliens. When participants press the start button, the largest alien in the ship at the top of the screen utters a word (X) and the two smaller aliens in the space ship 'repeat' it one after the other (A then B). The task of the participant is to click on the alien at the bottom of the screen who says the same word as the larger alien on the top half of the screen.

To ensure that participants understood the task and were able to perform it, there was a training session at the beginning of the programme. For this, real words were used which only differed in the initial phoneme, e.g. 'tin' and 'bin'. The practice words were high-frequency words of consisting of one CVC syllable or two CV syllables. Again participants were asked to adjust the loudness to a comfortable level during the training phase. During this phase feedback was also given by the programme: participants heard 'well done' if they were correct and 'try again' if they were not; the programme then played the same trial again. If a participant had more than four incorrect trials during the practice session, the session was repeated once more. If the participant still had more than four incorrect trials, testing was discontinued and he or she was excluded from the experiment, as it was not possible to establish whether the participant had fully understood the task.

The task contained four blocks with nine trials. Between blocks, a clown popped up and danced on the screen as a reward for completing a block. A total of 36 trials were presented over the four blocks: in 18 of those the 'same' stimulus was presented as A, whilst for the other 18 it was B. This was counterbalanced across the four blocks. Each block contained one trial for each type of variable and length, i.e. one each of two, three and four syllables *word stress*; two, three and four syllables *weak initial* as well as for *weak final*. These were randomised within each block and counterbalanced across blocks. The order in which the four test blocks were presented was counterbalanced within each participant group.

As can be seen in TABLE 3, the variables are investigated by presenting participants with stimuli which only differ in the experimental variable: in the category of word stress, stimuli are minimal stress pairs, e.g. [s@"na:] – ["sa:n@]. For weak ini-

	Perception of weak initial syllables	Perception of weak final syllables	Perception of word stress
2 syllables	səˈlɑ: - ˈlɑ:	ˈlɑ:sə - ˈlɑ:	səˈnɑ: - ˈsɑ:nə
	lɪˈɹɒ: - ˈɹɒ:	ˈɹɒ:lɪ - ˈɹɒ:	dəˈpɒ: - ˈdɑ:pə
	səˈnɑ: - ˈnɑ:	ˈnɑ:sə - ˈnɑ:	ləˈsɒ: - ˈlɑ:sə
	nəˈsɒ: - ˈsɒ:	ˈdɑ:pə - ˈdɑ:	ɹəˈlɪ: - ˈɹɒ:lɪ
3 syllables	fɪˈdʌpə - ˈdʌpə	ˈdʌpəfɪ - ˈdʌpə	ˈmʊlɪnə - məˈlɪnə
	nəˈmʊ lɪ - ˈmʊ lɪ	ˈmʊlɪnə - ˈmʊlɪ	ˈfɪpədə - fɪˈpʌdə
	kɪˈgɪbə - ˈgɪbə	ˈgɪbək1 - ˈgɪbə	ˈlʌsəpɪ - ləˈsʌpɪ
	dəˈfɪpə - ˈfɪpə	ˈfɪpədə - ˈfɪpə	ˈgɪbəkɪ - gɪˈbʌkɪ
4 syllables	fɪˈdʌpələ - ˈdʌpələ	ˈfɪdəpʌlə - ˈfɪdəpʌ	ˈfɪdəpʌlə - fɪˈdʌpələ
	dəˈfɪpəʃ1 - ˈfɪpəʃ1	ˈdʌfɪpəʃɪ - ˈdʌfɪpə	ˈdʌfɪpəʃɪ - dəˈfɪpəʃɪ
	kɪˈgɪbənə - ˈgɪbənə	ˈgɪbənəkɪ - ˈgɪbənə	ˈkɪgɪbənə - kɪˈgɪbənə
	nəˈmʊlɪdɪ - ˈmʊlɪdɪ -	ˈmʊlɪdɪnə - ˈmʊlɪdɪ	ˈnʌməlɪdɪ - nəˈmʌlɪdɪ

Table 3 | **Stimuli for each category**

tial syllables, the difference lies in the addition of a weak syllable at the beginning of the word, compare [s@"la:] with ["la:]. This is reversed for the perception of weak final syllables, where stimuli differ by the addition of a weak final syllable, e.g. ["da:p@] and ["da:]. TABLE 3 gives the stimuli for the three different lengths.

Stimuli

The stimuli were the same as for the NWREP. The speaker had recorded several tokens of each, and these were used for the XAB task. The stimuli were incorporated into the SIPC© XAB discrimination task software[53].

In reading the stimuli, the speaker paid close attention to keeping the same intonation, speech rate and loudness for each token. In addition, the first author used her perceptual judgments when choosing the stimuli for each trial to ensure that the stimuli only differed on the experimental variable.

Participants

The same participants who took part in experiment 1 also took part in experiment 2, except one female participant who did not pass the inclusion criterion of needing no more than two training blocks.

Procedure

A few weeks after having completed the first experiment, participants were again seen individually in a quiet room at their school or their home. A session took on average 15 minutes. The participants were told that the alien in the big ship at the top was the teacher, and that the two aliens in the little ships were pupils. The alien at the top would say a 'funny word' and the two lit-

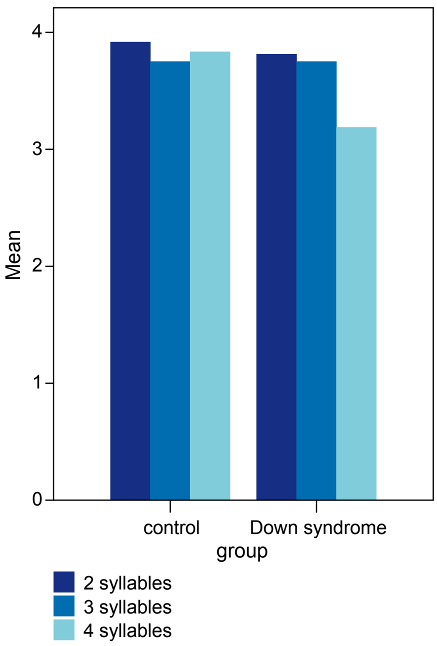

Figure 3 | **Average trials correct for both groups on perception of weak final syllables**

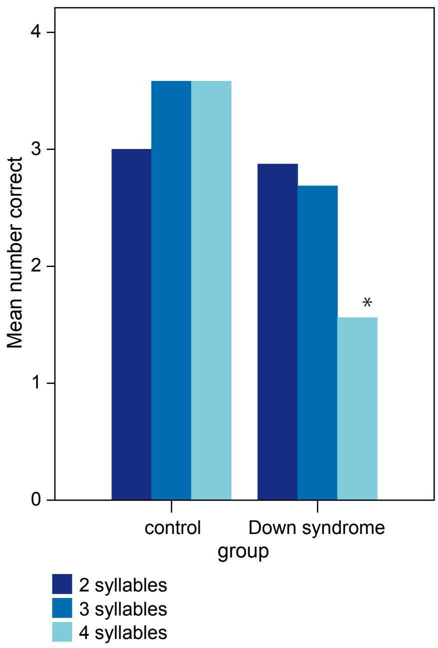

Figure 4 | **Average trials correct for both groups on perception of weak initial syllables**

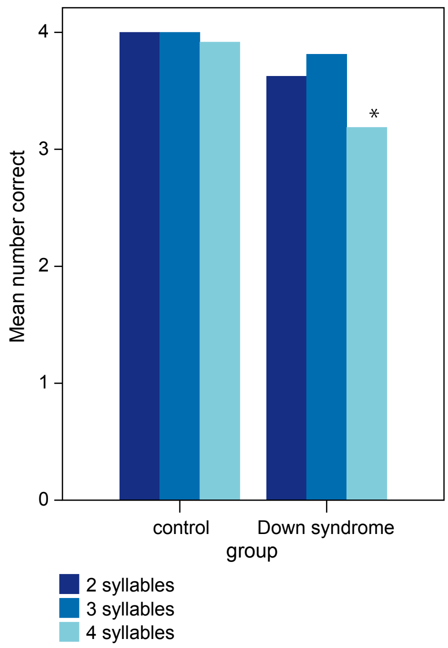

Figure 5 | **Average trials correct for both groups on perception of stress** tle ones would repeat it, but only one pupil would get it right. The participants' task was to decide which of the pupils was right.

Results

As in the previous experiment, the control group was at ceiling for each variable, and was therefore excluded from further analyses. The ceiling effect can be seen in FIGURES 3, 4 and 5 which show the average number of correct trials for each variable on the three different lengths for both groups. The clustered bars on the left represent the results of the control group.

An ANOVA with factors length (three levels: two, three and four syllables) and variable type (three levels: weak initial syllables, weak-final syllables and word-stress) was carried out to determine whether the performance of the participants with Down syndrome was affected by length and variable type. Both main effects were significant, length $F(2,28) = 55.27$; $p < 0.001$ and variable type $F(2,28) = 18.36$; $p < 0.001$, as well as their interaction $F(4,56) = 2.68$; $p < 0.05$. This shows that performance deteriorates with increasing length and differed according to the type of variable. To investigate where this significant interaction occurred, three post-tests were carried out with the alpha level adjusted accordingly (0.05/3 = 0.016). Paired samples t-tests compared performance on three- and four-syllable trials for weak-initial syllables, word stress and weak-final syllables. The first two were significant, weak-initial $t(14) = 3.69$, $p = 0.002$, word stress $t(14) = 3.56$, $p = 0.003$, while the comparison on weak-final syllables failed to reach significance after correction $t(14) = 2.55$, $p = 0.023$. This indicates that participants with Down syndrome were not affected in the same manner by length across all variables.

To explore the relation between hearing and performance on the discrimination task, the average for the better ear and overall score of each participant with Down syndrome were entered into a Spearman's Rank Correlation, which found no significant correlation $R(15) = 0.034$, $p > 0.05$.

Discussion

The first observation is that participants with Down syndrome were clearly able to perform the task, as evidenced by their scores on the two and three syllable items, which are close to ceiling and similar to those of the controls. Differences between the three experimental variables only emerged on the four syllable items, where memory load is greatest. For weak syllables, participants' discrimination was only significantly impaired when these were at the beginning of the word, whereas this was not the case for word-final weak syllables. Therefore it is not the case that weak syllables 'per se' are difficult to process, rather it is their position within the stress structure which renders them difficult. Interestingly, the perception of stress was also affected on longer items, in spite of the fact that this is a highly salient aspect of phonology and remains robust in noisy conditions[13,15,56].

It is difficult to argue that these effects were just to do with memory or auditory processing, as not all three variables were affected in the same way by word length. Rather, the performance on the discrimination task mirrors that on the production task: weak final syllables were never omitted from repetition and participants were also not significantly affected by length on their perception. Whereas weak initial syllables were frequently dropped and were also difficult to perceive on longer items. Similarly, the error patterns on the repetition task suggested that weak-initial forms and compound structures had not been acquired yet, and the high number of stress errors offer additional confirmation (see REFS 22,23,24,27). On the perception task, this was reflected by difficulties in perceiving changes to stress structure on longer items. This close match between perception and production match suggests an underlying difficulty with phonological representations.

The question remains as to why these difficulties only became evident on the longer items. We believe the explanation is twofold: all the participants with Down syndrome are adolescents who have good language levels and are all literate to varying degrees. These participants might well have had an earlier more severe difficulty with the processing of stress which would have been apparent on shorter items too. The difficulties on longer items seen in adolescence would therefore be remnants of an earlier more pervasive problem. Another possibility is that the stimuli were not difficult enough and that there were not enough trials. The speaker did produce the nonsense words quite deliberately and at a somewhat slow rate. Moreover, there were only four trials testing each variable in every length category, and a total of 36 trials is indeed rather short. The number of trials was kept small in order to avoid participant fatigue. Indeed some participants struggled with the length of the experiment, whilst the majority enjoyed it and asked for the game to continue. Clearly these results need to be replicated in order to be considered robust, and we are now in the process of creating a larger number of stimuli spoken at a faster rate.

Nevertheless we believe that the present findings offer a first indication that the perception of stress structure may be disrupted in children and adolescents with Down syndrome. This is especially interesting because similar problems with the perception of stress structures were found in infants at risk for SLI[6].

Conclusion

This paper presented two experiments which assessed the production and the perception of word stress and weak syllables in children and adolescents with Down syndrome. The results indicate that word stress and weak syllables which are in a difficult position in the stress structure (i.e. at the beginning of words) are not adequately encoded in the phonological system of these participants. Our findings are in accord with studies which suggest that underlying difficulties with the rhythmic and prosodic structure of speech are driving dysfluencies and reduced speech intelligibility in the speech of individuals with Down syndrome[38,40].

Nevertheless, the two experiments presented are only an initial exploration of stress processing in this population, and we do not claim that they represent a complete picture. Indeed our work does not show whether word stress is more affected than other aspects of phonology, nor is it clear whether these results represent a truly non-developmental pattern like that described in the work of Fikkert and Penner[1] and Shriberg et al.[3,4,5]. Another question relates to whether the difficulties with word stress are specific, or actually arise from problems with lower-level features that contribute to the phenomenon of word stress. Indeed Lee et al.[37] found less pitch variation in the intonation of participants with Down syndrome, and since pitch is an important indicator of word stress[56], this may well contribute to difficulties. Therefore more detailed phonetic investigations of word stress in this population are needed. Moreover, these studies should be conducted cross-linguistically, as different languages implement word stress differently[12]. Irrespective of questions concerning the specificity of the impairment, models of language acquisition predict considerable repercussions on language functioning from impaired processing of stress. We therefore consider what the present findings mean for language acquisition and their clinical implications.

Firstly, our results do not only uncover weaknesses in the linguistic system of participants with Down syndrome, but they also point to strengths: the experiments tested phonological processing in isolation from semantic and lexical effects; the results indicated that purely phonological processing in fact operates below their level of a receptive vocabulary equivalent to that of a child above the age of four years. Since by the age of four different stress structures have largely been acquired, the difficulties with weak-initial syllables and the inability to produce compound structures are indicative of a much younger phonological system. Interestingly, this also indicates strengths in lexical and semantic areas of language processing: in spite of having a phonological system which functions below the age of four, participants with Down syndrome still have a receptive vocabulary equivalent to that of a child over the age of four. Hence semantic and lexical factors must be compensating for deficits in phonological processing and scaffolding the receptive vocabulary. This pattern of strength in long-term storage and semantics versus relative weakness in the processing of linguistic structure is something that intervention methods in speech and language therapy and teaching practice for children with Down syndrome should take account of.

The impact of difficulties with the processing of word stress will be most severe if these are present from infancy: English-learning infants use their sensitivity to the predominant strong-weak stress pattern to divide continuous speech up into words[19]. A decreased sensitivity to stress structures will therefore render it more difficult to recognise words in continuous speech, which will slow down vocabulary acquisition. This slow start is predicted to have repercussions on syntactic development, since this is conditional on the vocabulary achieving a certain critical mass[57]. Furthermore, the participants in these experiments also had difficulties with the perception of weak-initial syllables. In connected speech, these will often be articles at the beginning of utterances. Christophe and collaborators have proposed a model of early language acquisition whereby infants use function words at the edges of utterances to build up their knowledge of syntactic structure[58,59]. If weak initial syllables are not perceived adequately by infants with Down syndrome, functions word such as determiners and articles will be affected, and if the model set out by Christophe et al. is correct, this will engender considerable delays in the acquisition of syntax.

Production problems with weak initial syllables will have a similar impact on the development of morpho-syntax, as phonological development is thought to interact with this: the majority of function morphemes are short words which do not carry main stress themselves but instead attach to the nearest stressed word, forming what is known as a 'phonological word' (see REF 60) for a detailed account). Hence they often occupy the position of a weak initial syllable before a stressed syllable, forming the more difficult weak-strong pattern which is acquired later. Gerken[55] compared sentences where the article 'the' preceded a strong syllable and therefore formed the more difficult weak-strong pattern (e.g. [the **dog**] [kissed her]) with sentences where it followed a strong syllable and was incorporated into a strong-weak pattern (e.g. [pete] [**kissed** the dog]). She found that children were much more likely to omit the article in the first type of sentences, where it occupied the difficult slot of a weak initial syllable. Moreover, in English a large number of verbs also has the more difficult weak-strong pattern[61], and this will contribute to difficulties with the processing of verbs[62,63], which in light of the pivotal role of verbs in the acquisition of syntax[64,65] again predicts considerable developmental delays.

In conclusion, we have shown the importance of stress to language processing, especially during the early stages of language acquisition. Since the experiments indicate potential difficulties with this crucial aspect of phonology, early stimulation methods and speech and language therapy may well need to place bigger emphasis on this often neglected area. In light of this it is particularly important to increase our knowledge of early speech perception abilities in infants with Down syndrome. Indeed, few studies exist on this topic, in spite of the fact that these infants are known to later develop language difficulties and are readily identifiable. Moreover, numerous theories of language breakdown postulate early deficiencies in phonological processing abilities in children with SLI[63,66,67], which renders the investigation of early abilities in Down syndrome even more pressing.

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