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Working title: Phonological markers of sentence stress in ataxic dysarthria and their relationship to perceptual cues

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1 Introduction

Ataxic dysarthria is a speech disorder caused by disturbances in cerebellar functioning. It can have a number of underlying causes, ranging from cerebellar degeneration (cerebellar/spino-cerebellar ataxia (CA/SCA), Friedreich's ataxia (FDA)) to cerebellar damage by stroke or toxicity. Darley, Aronson and Brown (1969a, 1969b) identified predominantly articulatory, prosodic and phonatory problems in their group of patients with cerebellar disease. They list the most deviant speech dimensions, in order of their severity, as imprecise consonants, excess and equal stress, irregular articulatory breakdown, vowel distortions, harsh voice, phoneme prolongations, monopitch and monoloudness, slow rate, excess loudness variations and voice tremor.

Subsequent research has confirmed Darley et al.'s (1969a, b) observations with a range of perceptual as well as instrumental methods. Studies focusing on segmental aspects report a range of impairments in vowel and consonant production in speakers with CA as well as FDA. More specifically, a reduction in vowel space contrasts has been reported (Baudelle, Vaissiere, Renard, Roubeau, & Chevrie-Muller, 2003; Chiu, Chen, & Tseng, 1996). In addition, segmental timing difficulties are frequently identified, such as a loss of distinction between voiced and voiceless plosives (Ackermann, Graber, Hertrich, & Daum, 1999; Ackermann & Hertrich, 1997; Blaney & Hewlett, 2007), as well as difficulties with vowel length (Ackermann et al., 1999; Blaney & Hewlett, 2007; Gentil, 1990).

Timing problems also feature strongly at the suprasegmental level. Ataxic dysarthria is generally associated with a slow speech rate, both in alternating/sequential movement rates as well as connected speech. This has been reported across FDA and CA (Ackermann & Hertrich, 1994; Folker et al., 2012; Gentil, 1990; Hartelius, Runmarker, Andersen, & Nord, 2000; Schalling, Hammarberg, & Hartelius, 2008; Wang, Kent, Duffy, & Thomas, 2009; Ziegler & Wessel, 1996). Probably the most distinctive symptom of impaired speech timing in ataxic dysarthria are the rhythmic disturbances experienced by many speakers, also referred to as scanning speech or syllable-timed rhythm. Acoustic-phonetic studies have identified a tendency towards more equalised vowel durations as one of the main contributors to this perceptual phenomenon, although other factors such as the reduced speech rate as well as altered loudness and pitch manipulations can also play a role (Hartelius et al., 2000; Henrich, Lowit, Schalling, & Mennen, 2006; Liss, White, Mattys, Lansford, Lotto, Spitzer, & Caviness, 2009; Schalling et al., 2008).

Further prosodic disturbances are associated with phonation. Boutsen, Duffy, Dimassi and Christman (2011), Schalling et al. (2008) and Kent et al. (2000) report phonatory problems for CA, including vocal tremor, and disturbances in periodicity and loudness and pitch variability. Similarly, Gentil (1990) reports sudden variations in pitch and loudness for speakers with FDA. Folker et al. (2012) furthermore observed strained-strangled or rough voice quality, combined with changes in signal-to-noise ratio in FDA speakers. Although a number of researchers noted that their participants presented with a highly variable profiles, possibly reflecting different underlying neurological symptom complexes, it can probably be argued that the majority of speakers with ataxia will experience phonatory disturbances at some stage of their disease progression. Combined with the timing difficulties described above, such problems can impact on the speaker's ability to use prosody in a linguistically meaningful way, such as focusing on important information in utterances, or signalling grammatical or pragmatic distinctions. Ataxic dysarthria can thus result in significant communication issues despite relatively unaffected segmental articulation patterns.

The above investigations are based on a variety of methodologies, including perceptual and acoustic analysis methods, structured versus more naturalistic speech tasks and detailed instrumental investigations as opposed to more global judgements on speech quality. The collation of results from this wide range of investigations has allowed researchers to establish what the main characterising features of ataxic dysarthria are. What is still lacking though is a good understanding of how exactly disturbances at the acoustic-phonetic level relate to perceived problems of expressing linguistic meaning and vice versa. Although a number of studies have incorporated several analysis levels, data have not necessarily been able to elucidate this relationship. Of the above studies into articulatory difficulties, only Blaney and Hewlett (2007) compared the results of segmental error analysis with overall intelligibility ratings of the same speakers, thus being able to indicate which segmental errors correlated most with the observed intelligibility deficit. Prosodic investigations present with similar methodological issues. Although Schalling et al. (2008) provide both perceptual and acoustic data, these were not correlated to aid the characterisation of their participants' speech performances. Similarly, Lowit, Kuschmann, MacLeod, Schaeffler & Mennen (2010) evaluated the phonetic characteristics of stress production in their speakers in the context of how well these contrasts had been perceived by listeners, but did not directly correlate the results with each other. There is thus a significant lack of research into the relationship between acoustic-phonetic measures and their perceptual correlates in ataxia dysarthria.

One area that has recently seen some progress in bridging this gap is research on intonation, where the application of the autosegmental– metrical (AM) framework (Pierrehumbert, 1980) has allowed researchers to investigate intonation from a phonological perspective and to relate these phonological representations to their phonetic correlates in order to make statements about the linguistic meaning. The AM framework interprets intonation contours as a sequence of meaningful local events around stressed syllables and phrase boundaries. This categorisation of intonation patterns allows researchers to systematically investigate the relationship between phonetic speech characteristics such as duration, intensity, and F0 modulations and their phonological manifestations. Kent and Kim (2003) highlight the value of this dual approach for the investigation of intonation deficits in motor speech. However, to date, only Kuschmann and Lowit (2012) have investigated this relationship in a systematic way in a small sample of speakers with Foreign Accent Syndrome (FAS). The study was able to establish differences between impaired speakers and healthy controls at both the phonetic and phonological level. More importantly though, it highlighted variations across the disordered population in the relationship between the two levels, which had distinct perceptual outcomes and warranted different treatment approaches. Kuschmann and Lowit (2012) were thus able to confirm the clinical value of such investigations in addition to contributing to our understanding of the disorders.

The current investigation aims to apply a similar approach to speakers with ataxic dysarthria. Lowit et al. (2010) had performed an acoustic-phonetic analysis of stress production tasks with speakers with CA and SCA, with one of the conclusions being that further phonological analyses have the potential to establish which of the phonetic deficits identified in their speaker groups were relevant to the perceptually observed impairment of linguistic functioning. The present study aims to close the loop by investigating the phonological repertoire of the same speakers and relate them to the perceptual and acoustic-phonetic findings of the 2010 study.

2 Method

2.1 Participants

The current investigation included eight speakers with ataxic dysarthria (AT) and eight age, gender and dialect matched healthy control (HC) speakers (see Table 1 for details). Two participants were excluded from the initial pool of ten speakers reported by Lowit et al. (2010), because their dysarthria was very mild and the previous phonetic analysis and perceptual evaluation revealed no differences to control speakers in their stress production.

All participants were monolingual speakers of either Standard Southern British English or Standard Scottish English. Hearing and vision of all participants were normal or corrected to-normal, and cognitive skills were adequate to complete the speech production experiment. The presence of ataxia in the clinical group was confirmed by a neurologist. Dysarthria was diagnosed by the first author based on performances across a range of standard speech and non-speech assessment tasks. Severity was determined from intelligibility scores derived from a passage reading task rated by five final year speech pathology students. Rating was performed via a visual analogue scale where listeners marked the degree of intelligibility on a 10 cm long line (with one end representing "completely intelligible" and the other "not intelligible at all"). Values presented in Table 1 represent the mean distance marked by listeners.

------------ *insert table 1 around here* ---------

2.2 Speech Production Task and Recording Procedure

The data reported here are based on the same task as in Lowit et al. (2010). The experiment was designed to investigate stress production across different sentence positions. Each speaker was asked to read a set of ten sentences, which were controlled for length, syntactic structure as well as lexical stress patterns (cf. appendix). Care was taken to include a maximum amount of voiced elements in order to facilitate the intonation analysis. Speakers produced the sentences either neutrally or with narrow stress in initial, medial or final position, resulting in data sets of 40 sentences containing 120 target words per speaker. The target words were all nouns. The randomized sentences were elicited using a question-answer paradigm, whereby contextual scenarios were designed to obtain stress in each of the sentence positions. A PowerPoint presentation was used in which the respective scenarios were presented in visual and auditory form. Each scenario was followed by a visual presentation of the target sentence, which participants were asked to read out. The word to be stressed in the different positions was underlined to ensure that a failure to emphasize the correct word could not be attributed to poor linguistic processing.

Speech recordings were made in a quiet environment in the participants' home or at university facilities using a portable DAT-recorder (TASCAM DA-P1) and a condenser microphone (Beyerdynamic MPC 65 V SW) at a sampling rate of 44.1 kHz. Data were subsequently digitised using Kay Elemetrics Multispeech System.

2.3 Speech Analysis

The phonological analyses were performed by the second author. Perceptual judgements were gained from five trained listeners (final year speech and language therapy students) who were familiar with dysarthric speech.

2.3.1 Phonological Analysis

The 640 sentence recordings were analysed using Praat speech analysis software. Annotation was conducted within the autosegmental-metrical (AM) framework of intonational analysis, which constitutes the dominant paradigm in current intonational research. The AM framework, primarily known through the seminal work by Pierrehumbert (1980, for a comprehensive overview see Ladd, 2008), regards intonation to be a combination of phonological and phonetic features. The phonological features of the intonation contour are described as sequences of H(igh) and L(ow) target tones. Tones that occur around phrase boundaries are boundary tones; tones that are associated with stressed syllables are referred to as pitch accents. They serve as perceptual cues to prominence (Ladd, 2008). Both types of tones are connected by phonetic interpolation. That is, the phonetic characteristics of the intonation contour determine how the phonological features of the speech stream are implemented. This duality of phonological representation and phonetic implementation is fundamental to the concept of the AM approach.

Based on the AM framework, a range of transcription systems were developed. Data annotation of the present study followed IViE (Intonational Variation in English), a variant of the AM transcription system developed for British English intonation (Grabe, 2004; Grabe, Nolan, & Farrar, 1998; Grabe, Post, & Nolan, 2001). IViE was chosen for this study as it allows the annotation of the participants' different dialects within one system. The data of the present study was annotated on six different levels (cf. figure 1): (1) a syllable by syllable orthographic transcription of the sentence, (2) a transcription of phrase boundaries (%) and prominent syllables (P), (3) a phonetic transcription of pitch levels (H/h = high, M/m = middle, L/l = low, capital letters mark pitch height on prominent syllables), (4) a phonological transcription of pitch accents and boundary tones, (5) an indication of which word was targeted for stress and (6) comments, e.g. hesitations, mispronunciations, etc.. The structural labels employed for this study included the following pitch accents: H* (high level pitch accent), L* (low level pitch accent), H*L (falling pitch accent), !H*L (downstepped falling pitch accent), L*H (rising pitch accent), L*HL (rise-fall pitch accent) and H*LH (fall-rise pitch accent).

Based on this transcription, the speech data were analysed using a variety of measures that have proven informative in previous studies on intonation in motor speech disorders (Kuschmann and Lowit, 2012; Kuschmann, Lowit, Miller & Mennen, 2012; Lowit & Kuschmann, 2012; Mennen, Schaeffler, Watt, & Miller, 2008). In particular four aspects of intonation were of interest: inventory, distribution, implementation and function.

The inventorial and distributional analyses established the type and prevalence of pitch patterns used to indicate stress on the target words in the different sentence positions. The analysis of the implementation patterns concerned the overall intonational realisation in terms of phrasing and accentuation. For phrasing, the mean length of intonation phrases (IP, measured in syllables) was established. For accentuation, the pitch accent - syllable ratio was measured, which reflects the frequency of pitch accents per utterance, with higher values reflecting a lower number of PAs per utterance. Function was analysed by examining how words in pre- and post-stressed positions were realized. That is, if the target word to be highlighted was in medial position, the pitch accentuation status of the noun in initial as well as final position was investigated. According to phonological theories, it is generally expected that stressed words will be assigned a pitch accent, whereas for unstressed words, this depends on the position within the utterance. In pre-stress position, i.e. before the stressed target word, unstressed words are commonly assigned a pitch accent for rhythmical reasons; in post-stress position unstressed words are expected to undergo de-accentuation, i.e. the word does not receive a pitch accent. There are no previous studies suggesting gender differences in any of the above analysis categories, and this factor was therefore not controlled for in the current study.

--- *Insert figure 1 around here* ---

2.3.2. Perceptual Analysis

The listeners performed two analyses for the speakers with ataxia, (1) an intelligibility rating, and (2) an evaluation of stress placement in the test utterances. They listened to each speech sample once before making a judgement. Listeners rated the perceived level of intelligibility of a reading passage on a visual analogue scale. The position of each judgement was then converted into a percentage score for statistical analysis purposes, i.e. a mark placed 7.5 cm into the 10 cm long scale was represented as 75% intelligibility. Accuracy of stress placement was assessed by asking listeners to underline which word they heard as being stressed in each utterance produced by the speakers. Results were grouped into correctly and incorrectly perceived utterances depending on the majority judgement, i.e. if three of the five listeners identified the target the utterance was classified as having correct stress placement.

2.5 Statistical Analysis and Reliability

Where relevant, results were checked for statistical significance using Mann-Whitney U test as well as the Spearman’s rho correlation coefficient. Non-parametric tests were chosen due to the small number of participants in each group.

Intra- and inter-rater reliability of the current data had been established as part of a larger pool of phonological analyses for speakers with ataxia and control speakers. Agreement rates were established for IP boundaries, prominent syllables (P) and classification of pitch accents. Intra-rater reliability, conducted by the second author was very high, with 100% agreement for IP boundaries, 91% for prominences, and 91% for the classification of pitch accents. Inter-rater analyses, carried out by a trained speech and language therapist, showed 83% agreement for IP boundaries, 93% agreement for prominences, and 80% agreement for type of pitch accent. The figures match or exceed previously reported inter-rater agreement results for intonation analyses (e.g. Pitrelli, Beckman, & Hirschberg, 1994).

To evaluate the reliability of listener judgements, intelligibility ratings were assessed by calculating the intraclass correlation coefficient (ICC, Shrout & Fleiss 1979). The ICC indicated good agreement between the five listeners (ICC: .942 with 95% CI (0.855, 0.984)).

3 Results

3.1 Phrasing and Accentuation

Analysis of mean IP length established that the control speakers produced significantly longer IPs than the speakers with ataxia (U=.000, Z=-3.373, p=.001). The data indicates that the latter split the target sentences on average into two or more phrases, whereas the control participants produced the sentences as one intonation phrase.

At the same time, the ataxic group produced more pitch accents per sentence than the control speakers (U=1.000, Z=-3.268, p=.001) as reflected by the pitch-accent syllable ratio analysis (cf. table 2, higher values indicate a greater number of syllables produced before the next pitch accent, and thus less pitch accents per utterance).

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3.2 Type and prevalence of pitch patterns

Figure 2 shows the type and prevalence of pitch patterns across the target words for the control participants and the ataxic group. Both participant groups made use H*L, H*, !H*L and L*H, with H*L being the most prevalent of these patterns. The statistical analysis revealed no group differences regarding these accents. On the other hand, differences were apparent in the use of the low pitch accent L* which was only produced by the control group, and de-accentuation, which occurred more frequently in their utterances (L*: U=4.000, Z=-3.243, p = .001, DE-A: U=.000, Z=-3.363, p=.001). Neither of the groups employed the tri-tonal pitch accents L*HL and H*LH.

------------- *insert figure 2 around here* ---------

As de-accentuation of unstressed words is more frequent in post- rather than pre-stress position, a more detailed evaluation of these items was performed. Figure 3 demonstrates that the majority of unstressed words in the control group were de-accented in post-stress position. In the few instances where control speakers did place a pitch accent they primarily used !H*L.

The ataxic group differed noticeably from this pattern. Some speakers still produced de-accentuation as their most common pattern, but considerably less often than the control speakers, whereas in others accentuation prevailed, with one speaker not producing any de-accentuation at all. In those cases where the speakers with ataxia placed an accent, these were predominantly H*L and !H*L, thus mirroring the pattern observed in the control group.

In summary, the speakers with ataxia differed from the control group in three main aspects, they produced short IPs, had more pitch accents per number of syllables, and de-accented less. A correlational analysis was performed to examine any potential relationships between these factors. The results indicate a strong relationship between IP length and PA/syllable ratio (r: .976, n = 8, $p<.01$), and also show significant correlation between IP length and de-accentation (r: .743, n = 8, $p<.035$). On the other hand, the relationship between PA/syllable ratio and de-accentuation was not significant (r: .659, n = 8, $p=.076$).

------------- *insert figure 3 around here* ---------

3.3 Analyses of individual de-accentuation patterns

Given the variability across the ataxic group in relation to the ability to de-accent, a more detailed investigation of individual performances was carried out by focusing on de-accentuation in relation to perceptual analysis of the speakers. In addition, the phonetic results previously reported on this participant group were revisited to establish their contribution to the observed speech patterns.

Table 3 provides individual results for frequency of de-accentuation, as well as percentage of utterances that were perceived with the correct stress pattern by the listeners. These values are again only based on those utterances including post-stress de-accentuation. They show that for most speakers with ataxia there was a close relationship between de-accentuation and perceptual results, i.e. listeners were able to identify the correct target word more often in those with a higher degree of de-accentuation than those who did not de-accent as much. There were two exceptions to this pattern, i.e. AT1 and AT2 had a low frequency of de-accentuation despite showing good perceptual scores. These two speakers thus appeared to be behaving differently to the rest the participants with ataxia. This assumption was confirmed by the statistical analysis, i.e. the correlation between the perceptual scores and the frequency of de-accentuation was not significant for the ataxic group as a whole (r:.282, n = 8, p =.498), unless AT1 and AT2 were excluded in which case values correlated highly with each other (r:.986, n = 6, p <.01).

------------- *insert table 3 around here* ---------

The limited use of de-accentuation yet successful marking of stress to listeners suggests that AT1 and AT2 must have used strategies other than de-accentuation to signal the location of the target words. In order to investigate this issue further, the phonetic results were revisited. These revealed that both speakers relied more heavily on duration and intensity and less on fundamental frequency to signal stress.

Figures 4a & b show the results of the percentage difference in duration and intensity between stressed and unstressed versions of the target words for initial and medial targets.

Final target utterances were excluded as no post-focal de-accentuation takes place in these positions. Positive values indicate the correct relationship between the two versions of a word, i.e. stressed targets are expected to be longer and louder than unstressed versions. Speakers AT1 and AT2 are plotted against control group means as well as against the mean of speakers AT7, 8 & 10, i.e. those speakers who also had a smaller number of de-accentuations than pitch accents. The figures demonstrate that, in addition to having poor control over pitch, AT7, 8 &10 did not succeed in manipulating duration and intensity effectively in sentence initial and medial position, i.e. stressed versions of target words were on average shorter than unstressed ones, and there was little difference in terms of intensity. On the other hand, AT1 and AT2 show durational and intensity differences more in line with or above control group means. AT1 appeared to rely more on durational contrasts, particularly in sentence initial position, whereas AT2 made more use of intensity differences between stressed and unstressed versions of the target words. This suggests that although these two speakers did not succeed in appropriately manipulating F0, as reflected in their lack of de-accentuation, they were able to compensate for their limited F0 control by making use of durational and intensity contrasts to a sufficient degree to signal stress position to the listeners in the majority of utterances.

------------- *insert figures 4a & b around here* ---------

4 Discussion

This study aimed to establish the relationship between the perceptual evaluation, the phonetic marking and the phonological use of intonation in the signalling of sentence stress in speakers with ataxic dysarthria. Adding the phonological component to the analysis of intonation in ataxic dysarthria is a novelty necessitated by the fact that in the past the exclusive examination of phonetics and perception did not always succeed in satisfactorily explaining their relevance for intelligibility and naturalness of speech. The phonological results of the present study show that in terms of accentuation, speakers of all three groups had the same types of pitch accents at their disposal but participants with ataxia differed significantly with regard to the number of pitch accents and the lengths of the IPs they realised. More specifically, the speakers with ataxia produced shorter IPs and accented more words than the control speakers, as reflected in a higherpitch-accent-syllable ratio as well as a lower rate of de-accentuation when marking stress in different sentence positions.

The availability of an equally rich repertoire of pitch accents in the speakers with ataxia and the control participants reflects previous findings on the same as well as other participant groups based on spontaneous speech data (Lowit & Kuschmann, 2012). This finding confirms previous suggestions that speakers with acquired motor speech disorders such as hypokinetic and ataxic dysarthria or FAS do make use of the same pitch patterns as healthy speakers (Kuschmann, & Lowit, 2012; Lowit & Kuschmann, 2012; Mennen et al., 2008; Verhoeven & Mariën, 2010). It further implies that differences in the perception of healthy and disordered intonation, in particular its functional use, are not the result of a limited pitch accent inventory. Rather, the findings of the present study suggest that the reason for the reduced ability to mark stress in the different sentence positions in some of the speakers with ataxia may be connected to the frequency of pitch accentuation and, related to it, de-accentuation. The current results demonstrate that the speakers with ataxia used de-accentuation to a significantly lesser degree than their healthy counterparts. A lack of de-accentuation in post-focal position can lead to a loss of distinction between stressed and unstressed words and thus impact on the speaker's ability to convey information effectively. This was confirmed by the perceptual analysis of the current data which showed that listeners' accuracy in identifying which word had been stressed decreased in proportion to the absence of de-accentuation in most speakers.

In summary, the current data confirm results from previous studies on different types of motor speech disorders and different speech tasks in highlighting that the distinction between normal and disordered intonation, and possibly also different levels of severity, is not based on the ability to produce particular pitch patterns, but to implement these appropriately in an utterance.

The performance of AT1 and AT2, who were able to compensate for their inability to manipulate F0 by effectively exploiting durational or intensity contrasts, is comparable to findings in a previous report on speakers with Foreign Accent Syndrome (Kuschmann, & Lowit, 2012). This group also included some individuals who were able to compensate for this problem by excessively manipulating duration and/or intensity, and who were consequently perceived as producing the correct stress patterns by listeners. The similarity in findings suggests parallels between different motor speech disorders in terms of how speakers realise intonation. In particular there appear to be two groups of speakers. There are those whose phonetic, phonological and perceptual results are closely related, and where impairment at the phonetic and/or phonological level corresponds to difficulties at the perceptual level. For example, AT7, 8 and 10 showed poor manipulation of the phonetic parameter F0 which manifested as a lack of de-accentuation at the phonological level and which lead to poor ability of listeners to identify the target word in an utterance perceptually. On the other hand, there are some speakers for whom the relationship between production and perception is altered due to the adoption of compensatory mechanisms. In the case of AT1 and AT2, for example, the loss of appropriate F0 manipulation and consequently the phonological distinction between accentuation and de-accentuation was successfully counteracted by manipulating other phonetic parameters more rigorously, thus resulting in a correct perceptual evaluation of their productions.

The fact that AT1 & AT2 were able to compensate for their problem is encouraging from a clinical point of view. It was furthermore interesting to see that both phonetic parameters were viable as compensatory strategies, i.e. one of these speakers made more use of duration whereas the other relied more on intensity to mark stress with equally successful results. Similar arguments have been put forward before, based on purely phonetic analyses. What our investigation of the phonological level adds to this is the fact that lack of distinction between stressed and unstressed words was not due to an insufficiency in, but rather an overproduction of pitch accents. This is very much in line with reports on rhythmic difficulties in ataxic dysarthria, i.e. the feature of equalised stress (Darley et al. 1969a, b), which is attributed to assigning too much prominence to normally unstressed syllables in individual words (Duffy 2013). However, the fact that a similar phenomenon has been observed in other speakers with acquired motor speech difficulties (Lowit & Kuschmann 2012) points to over-accentuation originating from a broader underlying deficit than purely cerebellar disturbances. From a clinical point of view, there appear to be at least two options to treat the observed problems. One is the traditional way where speakers are asked to overemphasise the important words in an utterance, thus making them more prominent than the rest even though all words are accented. This would mimic the strategy naturally implemented by AT1 and AT2. Another option might be to work on de-accentuation, i.e. rather than increasing effort on the word to be highlighted, the speaker could be asked to reduce the prominence of the remaining words in the utterance. Different phrasing of utterances might help to achieve this, as our results suggested a relationship between phrase length and de-accentuation patterns as well as the number of pitch accents produced. In either case, more control over the speech output is required, but the latter strategy might be more suitable for speakers for whom increased effort is not an option. In addition, it might result in more natural, less exaggerated speech. To answer such questions, further studies need to be performed that investigate a wider range of speakers with a comprehensive, multilayered analysis such as suggested here.

It may be unrealistic to expect clinicians to perform a detailed analysis of their patients' speech comparable to the current investigation, particularly if acoustic data analysis is required as part of such an analysis. However, we hope that a greater awareness of the various components involved in producing stress and intonation, and how their manipulation or lack thereof manifests at the various levels of analysis can enhance the specificity of clinical assessment and potentially lead to more refined treatment approaches.

5 Conclusion

In conclusion, our analysis has implications both for future research as well clinical practice. From a theoretical stance, we hope to have demonstrated the value and importance of investigating performance at all possible levels of production. Failure to collect perceptual data can lead to misinterpretation of observed behaviours at phonetic or phonological levels. In turn, a lack of phonetic data can lead to poor understanding of the underlying causes for any observed phonological or perceptual deviations. Finally, the phonological level represents the link between phonetic and perceptual data and allows us to identify why certain phonetic patterns lead to perceptions of abnormality whereas others result in successful communication.

In clinical terms, whilst we acknowledge that a complex phonological and phonetic analysis may not be realistic in this setting, it is hoped that raising the level of awareness of the complex and multi-level nature of stress production might go some way towards a more refined analysis of clients with speech disorders, leading to more effective treatment plans being devised in future.

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Appendix: Stress Sentences & Contextual Scenarios

Sentence Set

1. The gardener grew roses in London.
2. The landlord owned dwellings in Reading.
3. The minister has a nanny from Norway.
4. The model wrote her memoirs in Lima
5. The diva made a movie in Venice.
6. The lawyer met the model in London.
7. The widow bought a villa in Ealing.
8. The neighbour plays melodies on her mandolin.
9. The milliner got a memo from Melanie.
10. The murderer met his lover in Limerick.

Example Context:

Question:	**Answer:**
Do you know why Castle Terrace is under offer?	The **widow** bought a **villa** in **Ealing**.
Who bought a villa in Ealing?	The **widow** bought a villa in Ealing.
What did the widow buy in Ealing?	The widow bought a **villa** in Ealing.
Where did the widow buy a villa?	The widow bought a villa in **Ealing**.

The first context requires stress on all three target words as they all represent new information (see words highlighted in bold) in this case. The remaining three contexts require stress on a single sentence position (initial, medial and final).

Table and figure captions:

Table 1: Participant details for the speakers with ataxic dysarthria (AT) including age, gender and etiology (f=female, m=male; CA = cerebellar ataxia of undefined type, SCA = spinocerebellar ataxia (number indicates type of SCA), FDA = Friedreich's ataxia) and intelligibility score, as well as healthy control speaker (HC) age information. Intelligibility scores relate to the distance marked on a visual analogue scale towards the 100% intelligible end, i.e. the higher the value, the greater the intelligibility level.

Table 2: Overview of IP length and pitch accent-syllable ratio data per speaker group.

Table 3: Frequency of de-accentuation (in %) and percentage of perceptually correctly identified target words per speaker with ataxic dysarthria (AT).

Figure 1: IViE transcription example sentence showing the six annotation levels for one of the speakers with ataxic dysarthria (AT). Above the annotation levels the oscillogram (representation of sound wave) and the spectrogram (representation of frequency distribution) are displayed. The line in the spectrogram represents the pitch contour.

Figure 2: Type and prevalence (in %) of pitch patterns on both stressed and unstressed words per speaker group.

Figure 3: Type and prevalence (in %) of pitch patterns for unstressed words in post-stress positions per speaker group, indicating the median, the interquartile range, the maximum and minimum, as well as outliers (>1.5 times the interquartile range).

Figures 4a and b: Percentage difference in duration and intensity between stressed and unstressed versions of target words for initial (T1) and medial (T2) positions.

speaker	**age**	**gender**	**etiology**	**intelligibility**
AT1	46	m	CA	26
AT2	60	f	CA	33
AT4	52	f	CA	75
AT5	28	f	FDA	91
AT6	65	f	SCA6	42
AT7	72	m	CA	81
AT8	51	m	CA	56
AT10	56	m	SCA8	18
AT mean (SD)	*53.8 (13.3)*			
HC mean (SD)	*53.1 (12.4)*			

Table 1

	HC				AT			
	mean	median	SD	IQR	mean	median	SD	IQR
IP length (syll)	9.71	9.67	0.59	1.11	6.03	7.07	2.44	3.36
Pitch accent-syllable ratio	4.49	4.52	0.25	0.13	3.15	3.17	0.67	0.75

Table 2

speaker	AT1	AT2	AT4	AT5	AT6	AT7	AT8	AT10
frequency of de-accentuation	7	11	57	79	57	30	0	24
% correctly identified target	100	100	80	100	81	75	45	65

Table 3

Learning outcomes

After reading this article the reader will be able to 1) explain the relevance of phonology and phonetics in the perception of stress production in ataxic dysarthria; 2) describe the different levels of intonational analysis; and 3) understand the observed intonation patterns in ataxic dysarthria as well as the compensatory mechanisms speakers may adopt to produce stress

Highlights

- we investigated features of stress production in ataxic dysarthria
- phonological methods were applied and compared to perceptual results
- results show problems with de-accentuation in most speakers with ataxia
- however, some participants successfully implemented compensatory strategies
- study highlights importance of investigating prosodic impairment at several levels

CEU Questions

1. Which of the following analysis levels does NOT form part of the 4 tier model of intonational analysis?

a. inventory

b. discrimination

c. implementation

d. function

2. What are the main acoustic parameters involved in stress marking?

a. Pitch, loudness and length

b. Pause, loudness and length

c. Pitch and loudness

d. None of the above

3. The autosegmental metrical framework is a methodology to analyse

a. Segment durations

b. Stress production

c. Intonation

d. Rhythm

4. De-accentuation is the phonological correlate of which parameter?

a. Loudness

b. Length

c. Pitch

d. All of the above

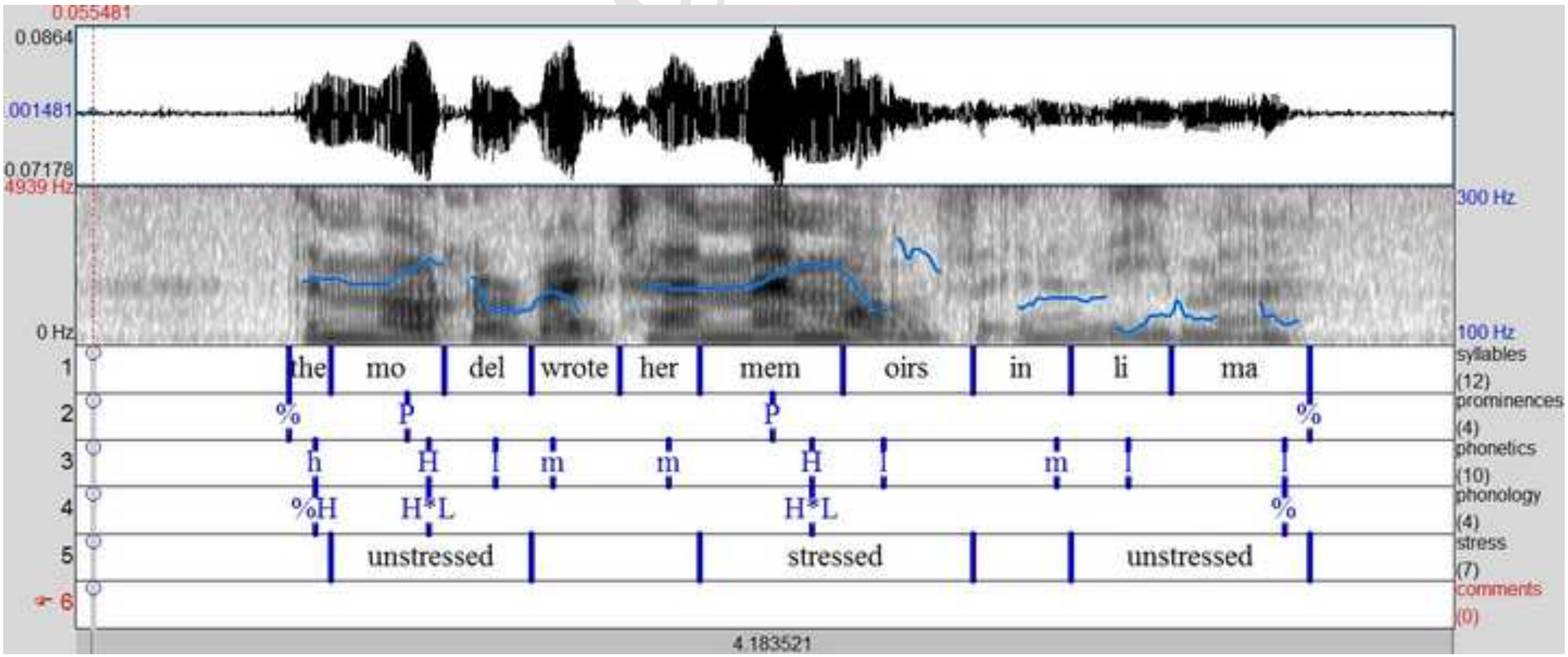
5. Speakers with motor speech disorders have a tendency to produce too few pitch accents.

    - TRUE/FALSE

Answer key:

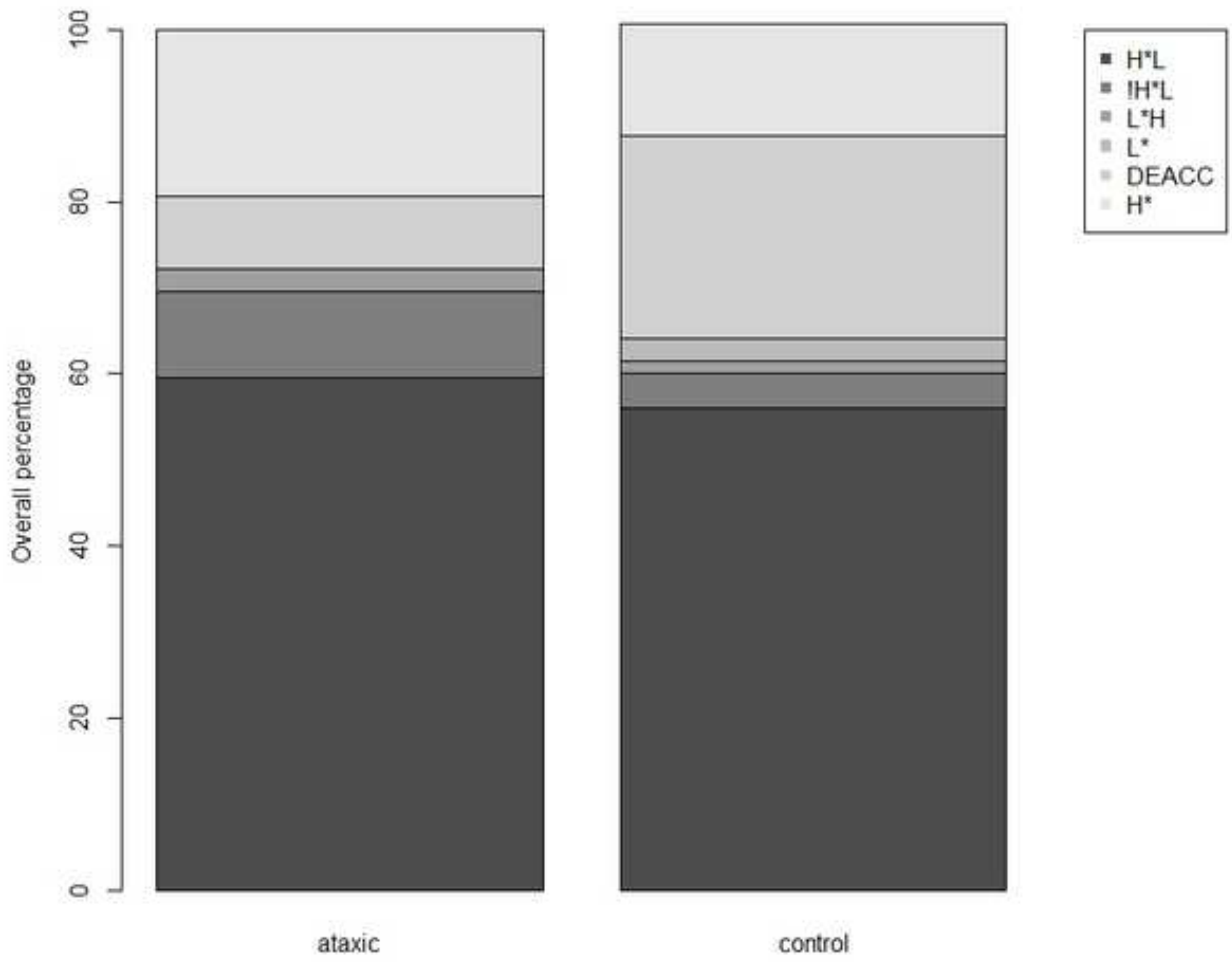
1b, 2a, 3c, 4c, 5 FALSE

Figure



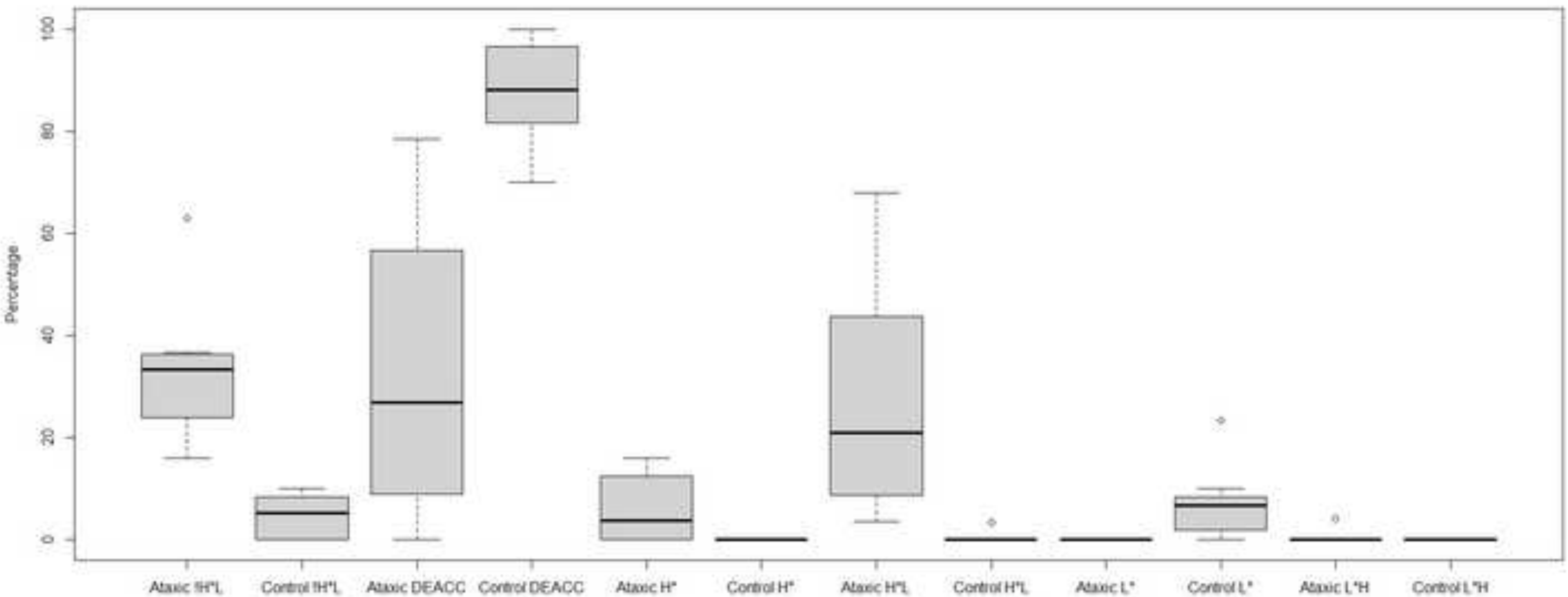
0.055481
0.0864
.001481
0.07178
4939 Hz
0 Hz
300 Hz
100 Hz
the mo del wrote her mem oirs in li ma
% P P %
h H l m m H l m l l
%H H*L H*L %
unstressed stressed unstressed
syllables (12)
prominences (4)
phonetics (10)
phonology (4)
stress (7)
comments (0)
4.183521

Figure



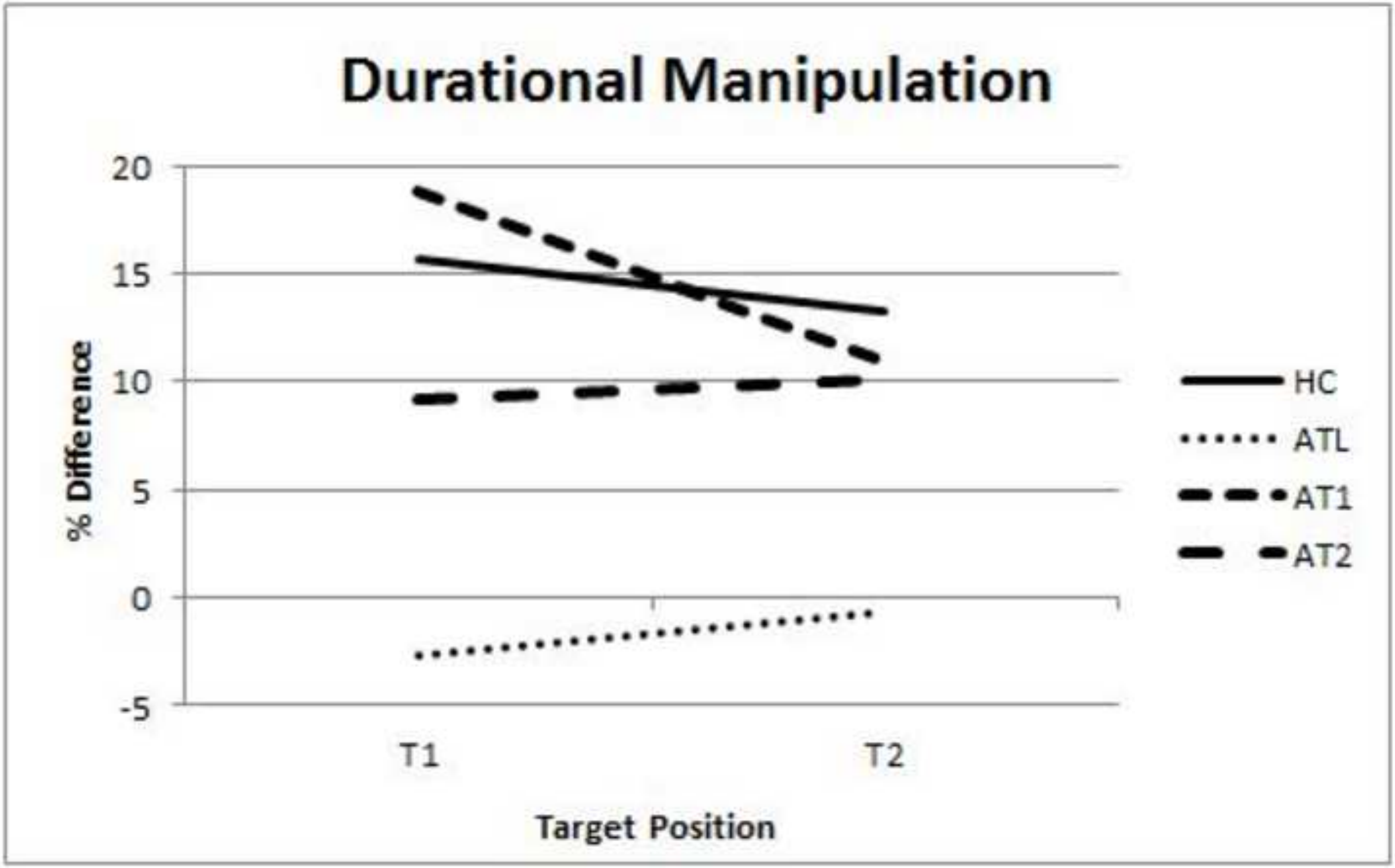
Overall percentage
100
80
60
40
20
0
ataxic
control
H*L
!H*L
L*H
L*
DEACC
H*

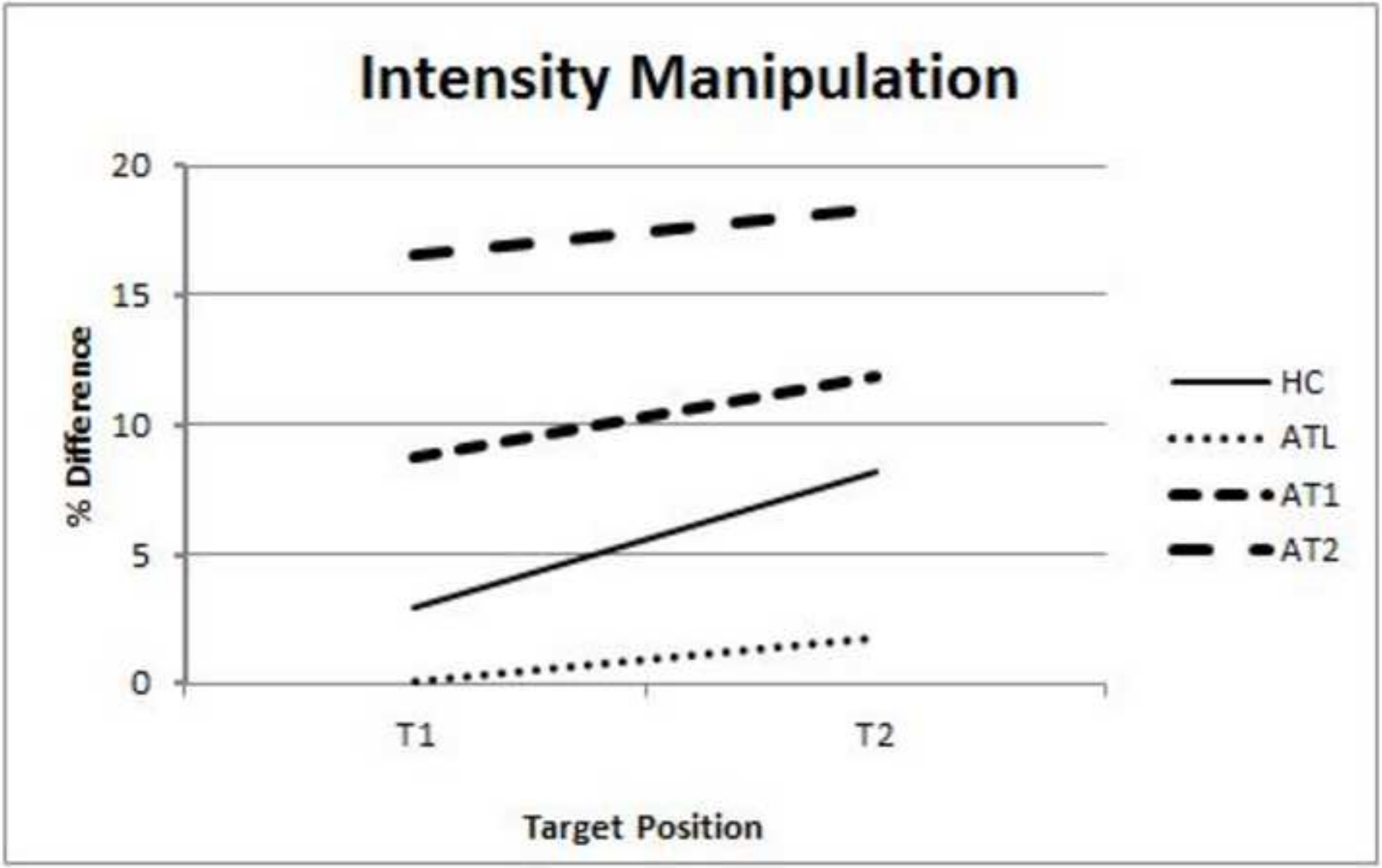
Figure



Percentage
0
20
40
60
80
100
Ataxic !H*L
Control !H*L
Ataxic DEACC
Control DEACC
Ataxic H*
Control H*
Ataxic H*L
Control H*L
Ataxic L*
Control L*
Ataxic L*H
Control L*H

Figure


Durational Manipulation
20
15
10
5
0
-5
% Difference
T1
T2
Target Position
HC
ATL
AT1
AT2


Intensity Manipulation
20
15
10
5
0
% Difference
T1
T2
Target Position
HC
ATL
AT1
AT2