


## Research Report

# Effect of boost articulation therapy (BArT) on intelligibility in adults with dysarthria

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### Abstract

**Background:** The articulatory accuracy of patients with dysarthria is one of the most affected speech dimensions with a high impact on speech intelligibility. Behavioural treatments of articulation can either involve direct or indirect approaches. The latter have been thoroughly investigated and are generally appreciated for their almost immediate effects on articulation and intelligibility. The number of studies on (short-term) direct articulation therapy is limited.

**Aims:** To investigate the effects of short-term, boost articulation therapy (BArT) on speech intelligibility in patients with chronic or progressive dysarthria and the effect of severity of dysarthria on the outcome.

**Methods & Procedures:** The study consists of a two-group pre-/post-test design to assess speech intelligibility at phoneme and sentence level and during spontaneous speech, automatic speech and reading a phonetically balanced text. A total of 17 subjects with mild to severe dysarthria participated in the study and were randomly assigned to either a patient-tailored, intensive articulatory drill programme or an intensive minimal pair training. Both training programmes were based on the principles of motor learning. Each training programme consisted of five sessions of 45 min completed within one week.

**Outcomes & Results:** Following treatment, a statistically significant increase of mean group intelligibility was shown at phoneme and sentence level, and in automatic sequences. This was supported by an acoustic analysis that revealed a reduction in formant centralization ratio. Within specific groups of severity, large and moderate positive effect sizes with Cohen's *d* were demonstrated.

**Conclusions & Implications:** BArT successfully improves speech intelligibility in patients with chronic or progressive dysarthria at different levels of the impairment.

**Keywords:** dysarthria, intelligibility, segmental articulation therapy.

### What this paper adds

#### *What is already known on the subject*

- Behavioural treatment of articulation in patients with dysarthria mainly involves indirect strategies, which have shown positive effects on speech intelligibility. However, there is limited evidence on the short-term effects of direct articulation therapy at the segmental level of speech. This study investigates the effectiveness of BArT on speech intelligibility in patients with chronic or progressive dysarthria at all severity levels.

#### *What this paper adds to existing knowledge*

- The intensive and direct articulatory therapy programmes developed and applied in this study intend to reduce the impairment instead of compensating it. This approach results in a significant improvement of

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speech intelligibility at different dysarthria severity levels in a short period of time while contributing to exploit and develop all available residual motor skills in persons with dysarthria.

*What are the potential or actual clinical implications of this work?*

- The improvements in intelligibility demonstrate the effectiveness of a BAiT at the segmental level of speech. This makes it to be considered a suitable approach in the treatment of patients with chronic or progressive dysarthria.

## Introduction

Dysarthria is described by Darley *et al.* (1969, 1975) as a collective name for a group of speech disorders that are the result of disorders in muscular control of the speech mechanism, due to damage in the central or peripheral nervous system. It can affect all dimensions of speech, namely articulation, resonance, voice and prosody. Speech intelligibility is defined as the extent to which the acoustic signal produced by the speaker can be accurately captured by the listener (Hustad 2008). The impairments derived from the affected dimensions can lead to reduced speech intelligibility, causing misinterpretation, difficulty and communication problems. Subsequently, dysarthria has a major impact on the patient's participation in daily life and overall quality of life (Dykstra *et al.* 2007, Dickson *et al.* 2008).

Articulatory imprecision is considered a key feature of dysarthria (Tjaden 2007) reflected by perceptual characteristics such as irregular articulatory distortions, distortion of vowels and extended phonemes (Duffy 2019). Reduced and uncoordinated articulatory displacements, due to slow, weak, imprecise and uncoordinated movements of the speech musculature, result in reduced acoustic contrasts for vowels and consonants, which in turn is linked to reduced speech intelligibility (Yorkston 1996, Tjaden 2007). De Bodt *et al.* (2002) showed that articulation contributed considerably more to speech intelligibility than other speech dimensions. It can, therefore, be concluded that addressing articulation problems is an important objective in the disorder-oriented treatment of dysarthria. In fact, Miller and Bloch (2017) show that articulation therapy is often selected by speech–language pathologists to treat their patients with dysarthria, independently of the severity of impairment.

Behavioural treatment of articulation can involve either a direct or an indirect approach. Direct methods focus on the segmental level of speech and aim to alter the identity of phonemes, whereas indirect methods focus on the suprasegmental level meaning that the strategies are superimposed on individual phonemes or sequences of phonemes and the effect on articulation is only secondary to the primary aim. Examples of indirect

treatment methods are increased vocal intensity, changes in intonation and reduction of speech rate (Tjaden 2007).

Speech–language pathologists (SLP) select the most appropriate intervention method based on factors such as the type and severity of the dysarthria, the patient's own goals, and treatment preferences obtained by assessment (Palmer *et al.* 2007). Duffy (2019) states that although working to reduce impairment and compensate for impairment are both appropriate, clinicians' efforts are more frequently directed toward compensation. This was confirmed in a survey by Guns *et al.* (2009) and in a recent unpublished survey in which almost 70% of the 52 participating speech therapists indicated to prefer indirect treatment of articulation above phoneme-specific exercises (Van Nuffelen *et al.* 2019). A possible explanation could be the likelihood that compensation can be achieved more rapidly than the actual reduction of impairment (Duffy 2019).

This preference seems to be supported by a considerable and still increasing number of studies showing a positive effect of indirect treatment strategies on speech intelligibility and articulation. For instance, there is a suggestion that speech rate is one of the most modifiable variables for improving intelligibility (Yorkston *et al.* 1992). This statement was supported by Martens *et al.* (2015) who investigated the effect of intensive treatment of speech rate and intonation on the intelligibility of dysarthric patients due to Parkinson's disease and observed significant improvements of the intelligibility scores. Other studies where rate control techniques were investigated found similar effects (Yorkston and Beukelman 1981, Marcella *et al.* 1998, Hustad *et al.* 2003, Van Nuffelen *et al.* 2010). In addition, other behavioural therapy techniques seem to have a positive impact on intelligibility as well. The well-known Lee Silverman Voice Treatment program (LSVT<sup>®</sup>) appears to have a positive impact on articulatory precision, in particular vowel space area and speech intelligibility in persons with non-progressive dysarthria (Wenke *et al.* 2010). Sauvageau *et al.* (2015) confirmed an improved articulation of vowels and a better distinction of consonants as a result of increased

loudness. In Sapir *et al.* (2003), the results of a single-case study of ataxic dysarthria indicated a short- and long-term improvement in phonatory and articulatory functions, speech intelligibility and overall communication. Cannito *et al.* (2012) found improvements in sentence intelligibility in patients with Parkinson's disease. The above studies demonstrate that therapy with a focus on increasing loudness can have a positive effect across the speech mechanism without direct attention to other systems (Dromey *et al.* 1995, Sapir *et al.* 2007).

One of the most appealing aspects of indirect methods, such as loud, slow and clear speech, is their demonstrated instant effect (Tjaden *et al.* 2014, Levy *et al.* 2017, Van Nuffelen *et al.* 2010).

In contrast with the considerable amount of evidence on indirect treatment strategies, the number of studies on direct articulation therapy is limited. However, some studies indicate that direct articulation treatment is actually worth the effort. Moreover, there is even a possibility that the focus on compensating can actually counter the process of neural reorganization to reduce specific impairment (Dobkin and Thompson 2000). A study that compared the effect of the LSVT and a traditional direct intervention in non-progressive dysarthria patients revealed a short- and long-term significant increase in vowel space area and intelligibility following both treatments (Wenke *et al.* 2010). A single-case study by Hartman *et al.* (1979) investigated whether a patient with dysarthria as a result of a traumatic brain injury (TBI) would benefit from following a segmental articulation therapy. The results showed an improvement in the trained tasks and, in addition, the patient was able to generalize the correct articulation to untrained words. Another single-case study by Marchant *et al.* (2008) compared the effect of phonetic placement therapy (PPT) and surface electromyography (sEMG) biofeedback-facilitated relaxation therapy in a child with severe spastic dysarthria. Results showed a significant improvement in word intelligibility after following the PPT. However, no perceptual improvement was observed in overall intelligibility with the severity of dysarthria suggested as a possible cause.

It can be concluded that if the patient still has the neural and muscular potential to improve speech function, an appropriate therapy can facilitate that process. It is therefore important to further explore whether patients with chronic or progressive dysarthria can benefit from an intervention on the segmental level and whether even short, boost articulation therapies (BAiT) are worth the effort.

A key feature of boost therapies is intensity, one of the main principles of motor learning and neuroplasticity which are generally acknowledged as key for speech therapy (Rosenbek and Jones 2009, Kaipa 2016, Duffy 2019). Several studies have already shown that intensive

treatment of dysarthria is beneficial for long-term carry-over (Jones *et al.* 1999, Nudo *et al.* 2000, Ramig *et al.* 2001, Bhogal *et al.* 2003, Kleim *et al.* 2003, Fox *et al.* 2006, Mackenzie and Lowit 2007, Mackenzie *et al.* 2014, Miller 2014). Intensity can be achieved via the frequency of treatment, repetitions within sessions or in requiring greater force, effort or accuracy during motor tasks. Other important aspects are continued practice needed for long-term structural changes in neural functioning and sensory feedback (Kleim *et al.* 2003, Garvey *et al.* 2007, Kleim and Jones 2008, Maas *et al.* 2008).

To date, there are few studies that combine the principles of motor learning with a segmental approach to traditional articulation therapy. This research aims to explore this further on the basis of the research questions:

Can BAiT significantly improve speech intelligibility in chronic or progressive dysarthria?

Is there a significant impact of dysarthria severity on the outcome?

## Materials and methods

The study consists of a two-group pre-/post-test design to assess the speech intelligibility of patients with chronic or progressive dysarthria before and after intensive articulation therapy on the segmental level, after one week of therapy.

### Participants

Patients were recruited at the University Hospital of Antwerp and private practices by convenience sampling. In order to participate in the study, the patients had to be adults (> 18 years of age), native speakers of Dutch, with a diagnosis of chronic or progressive dysarthria due to neurogenic origin and with a score < 90% at the Dutch phoneme Intelligibility Assessment (DIA—a synonym for the abbreviation NSVO in Dutch) (De Bodt *et al.* 2006). Articulation therapy during the last six months was set as an exclusion criterion.

A total of 17 Dutch-speaking subjects with dysarthria (11 men and six women) were included. Table 1 displays subjects' characteristics and the test results of the Dutch version of the Montreal Cognitive Assessment test (MoCa) (Thissen *et al.* 2010) and the Speech Handicap Index (SHI) (Van den Steen *et al.* 2011).

### Intervention

The participants were randomly assigned to either the articulatory drill programme (BAiT-AD) or the minimal pair programme (BAiT-MP). Drill refers to the systematic training of specially selected and ordered exercises (Duffy 2019). It is a consistent way

**Table 1. Characteristics of the participants**

Participant	Intervention <sup>Notes: a</sup>	Sex	Age (years)	Neurological pathology	Type of dysarthria	Severity dysarthria	MoCa score <sup>b</sup>	SHI score <sup>c</sup>
1	AD	Male	56	Idiopathic	Flaccid	Mild	24	27
2	AD	Male	55	Cerebellar ataxia	Spastic	Mild	24	32
3	AD	Male	38	Steinert disease	Hypokinetic	Moderate	25	24
4	AD	Male	60	Idiopathic	Mixed	Severe	29	42
5	AD	Female	36	Friedreich ataxia	Atactic	Mild	28	18
6	AD	Female	84	ALS	Mixed	Severe	18	42
7	AD	Female	72	Parkinson's Disease	Hypokinetic	Severe	22	50
8	AD	Female	75	Parkinson's Disease	Hypokinetic	Mild	21	41
9	MP	Male	81	Idiopathic	Flaccid	Severe	22	37
10	MP	Male	98	Parkinson's Disease	Hypokinetic	Moderate	25	22
11	MP	Female	85	ALS	Mixed	Severe	26	39
12	MP	Male	35	Friedreich ataxia	Atactic	Moderate	27	12
13	MP	Male	63	Parkinson's Disease	Hypokinetic	Mild	27	19
14	MP	Male	81	Steinert Disease	Hypokinetic	Moderate	21	26
15	MP	Male	70	Idiopathic	Flaccid	Moderate	25	9
16	MP	Female	92	TIA	Mixed	Severe	20	25
17	MP	Male	53	Parkinson's Disease	Hypokinetic	Mild	25	23

Notes: a Intervention: AD, articulatory drill; and MP, minimal pairs.

b Score of the cognitive test Montreal Cognitive Assessment (score range: 0–30, score  $\geq 26$  = normal cognitive functioning).

c Score of the Speech Handicap Index (score range: 0–60; score < 14 no impact, 14–22 light, 23–31 moderate, > 31 severe impact).

ALS, amyotrophic laterals sclerosis; TIA, transient ischemic attack.

of practising. When training on minimal pairs, a form of variable practice, two sounds that differ on one distinctive feature are linked together (Bauman-Waengler 2004). Both articulatory drill and minimal pairs were selected for the same goal, namely, to push and stimulate the motor circuits to articulate more precisely and consequently reduce sound distortions. Participants practised five sessions of 45 min during one week with each session addressing a patient-specific target sound based on the qualitative analysis of the NSVO.

Figure 1 illustrates the design of both BArT-AD and BArT-MP. For each target sound, the programme incorporates three exercise sections with the target sound (BArT-AD) or distinctive contrast (BArT-MP) respectively in an initial, medial/final position and in mixed position. The sections need to be completed in consecutive order starting with the initial position.

The sections are further divided into four levels with increasing difficulty and decreasing feedback. The patient starts with training on level 1, receiving feedback from the SLP after each word (BArT-AD) or each minimal pair (BArT-MP).

At each level, the therapist gives solely feedback on the first set of words or word pairs. For the remaining two sets, the patient first must do a self-perception assessment (i.e., internal feedback) and only subsequently receives delayed external feedback from the SLP. The therapist offers several types of feedback, such as auditory and visual modelling, phonetic placement with pictural support, verbal phonetic placement, clear speech and vivid speech. During the training, there is a gradual reduction of feedback frequency. Figure 1 shows a summary of both intervention programmes. The well-delineated design and sequence of the therapy programmes were respected during each session.

The stimuli of the training programme were carefully selected from the book *Articulation in Practice* (Huybrechts 1999) and the official word inventory of Dutch (Renkema 1995). They were presented to the patients by means of a PowerPoint presentation. The target sound was highlighted by putting it in bold. During the training, the therapist scores the words of the last set. If the patient scores < 50% in the last set of the first level, level 0 is passed through once. If the patient

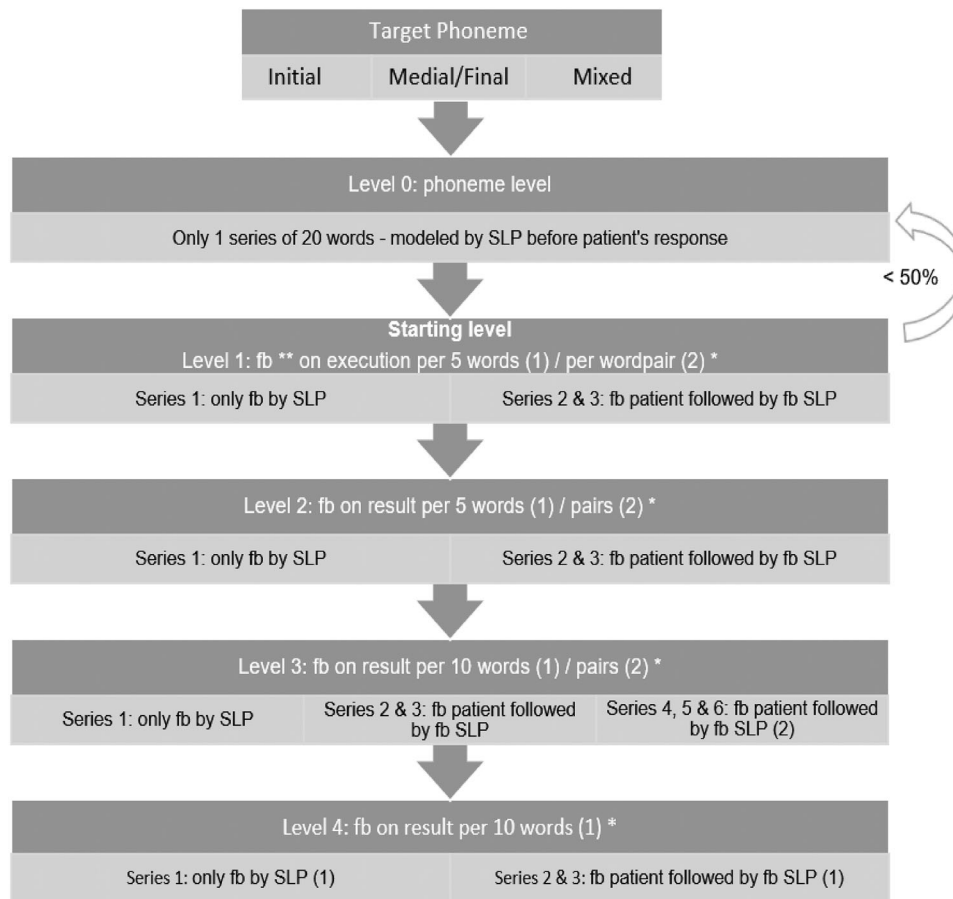


Figure 1. Intervention design. Components with '(1)' are exclusively intended for the intervention articulatory drill; components with '(2)' are intended for the intervention of minimal pairs; and when nothing is included, the parts are common for both interventions. \*The SLP scores each word by means of a scoring form; and \*\*feedback.

fails again on the first level, but a correct self-perception was noted, the patient may proceed to level 2. In case of an incorrect self-perception, the training continues with another target sound to be practised.

#### Perceptual assessment

The baseline measurements were collected 1–3 days before the start of the therapy programme, the post-treatment speech status of the patients was assessed immediately after the therapy programme, in order to evaluate short-term effects.

Five speech tasks were included: (1) a standardized speech intelligibility assessment at the phoneme level (NSVO), (2) a standardized sentence intelligibility assessment (NSVO-Z), (3) spontaneous speech, (4) automatic speech (counting to 10 and listing the weekdays) and (5) reading the phonetically balanced text 'De Auto' (Martens *et al.* 2010).

Intelligibility was perceptually judged in all the speech tasks by three experienced SLP's. Tasks 3–5 were presented randomly and judged by means of visual ana-

logue scales (VAS). The average score of the measures was used for further analysis.

#### Recording procedure

Speech samples were recorded before and after treatment in a quiet environment, with a high-quality headset microphone (Plantronics Blackwire 5210) positioned at a mouth distance of 5 cm, connected to a computer, and using the freely available software Audacity v.2.3.3 (sampling rate 44.1 kHz with 24-bit quantization, mono) (Audacity Team 2019).

#### Acoustic analysis

Besides perceptual assessments, an acoustic analysis was performed to objectively evaluate the treatment effects of the intervention programme. The F1, F2 formant frequencies can be used to describe the articulatory movements of the tongue, jaw and lips (Kent *et al.* 1999), and the vowels /a/, /i/, /u/ often represent the extremes of articulatory goals. There are some commonly



used methods to quantify vowel production clinically and have been used to characterize vowel articulation impairment showing promising results. One of those methods is the Formant Centralization Ratio (FCR), a sensitive, valid and reliable acoustic measurement designed to calculate vowel centralization with reduced sensitivity to inter-speaker variability (Sapir *et al.* 2010, Caverlé *et al.* 2020). The FCR is applied in this study for monitoring treatment effects, as a supportive measure to perceptual evaluations. An FCR score of approximately 1 is considered to be a normal value for a healthy speaker, for dysarthric speech higher scores are expected (2 as a maximum) due to a smaller vowel quadrilateral. A decrease in vowel centralization would be expected following an effective treatment of the dysarthria. The formula to calculate FCR is represented as:

$$(F2u + F2a + F1u + F1i) / (F2i + F1a)$$

where F1 and F2 represent the first and the second formants of the vowels, respectively.

The acoustic analysis was performed using Praat software v6.1.09 (Boersma and Weenink 2020) running on Windows OS. Acoustic segmentations were conducted taking into account intensity and pitch period. The vowels /a/, /i/ and /u/ were analysed from representative items of the NSVO assessment, pre- and post-therapy. The mean frequency values of the formants F1 and F2 were measured in the temporal midpoint of each vowel, where the energy reaches maximum intensity.

### Statistical analysis

The statistical analysis was completed by means of the computer programme IBM Statistical Package for the Social Sciences v.26 (IBM SPSS 26). A Shapiro–Wilk test was used to investigate the normality of distribution. A mixed-design analysis of variance (ANOVA) was used to verify possible between-groups (articulatory drill versus minimal pairs) differences. Mixed-models' effects were used to analyse the effect of BArT in time with post-hoc analysis to investigate the effect of severity of impairment; the Bonferroni–Holm correction was applied for multiple testing. To account for the small sample sizes, effect sizes (Cohen's *d*) were calculated. The relationship between acoustic and perceptual evaluations was verified by means of correlation. A significance level ( $\alpha$ ) of  $p = 0.05$  was used for all statistical analyses.

### Ethics permission

The clinical trial was approved by the Independent Commission for Medical Ethics 'Ethics Committee Antwerp University Hospital'. All participants agreed

**Table 2. Summary of effect sizes of each speech tasks and time point for intelligibility ( $n = 17$ )**

	Baseline	Post-measurement
<b>NSVO</b>		
Mean $\pm$ SD	72 $\pm$ 14	78 $\pm$ 16
<i>p</i> -value		<b>0.008</b>
Cohen's <i>d</i>		0.41
<b>NSVO-Z</b>		
Mean $\pm$ SD	69 $\pm$ 25	75 $\pm$ 21
<i>p</i> -value		<b>0.012</b>
Cohen's <i>d</i>		0.27
<b>Spontaneous speech</b>		
Mean $\pm$ SD	56 $\pm$ 32	60 $\pm$ 30
<i>p</i> -value		0.075
Cohen's <i>d</i>		0.13
<b>'De Auto'</b>		
Mean $\pm$ SD	67 $\pm$ 26	70 $\pm$ 27
<i>p</i> -value		0.292
Cohen's <i>d</i>		0.12
<b>Automatic sequences</b>		
Mean $\pm$ SD	77 $\pm$ 22	81 $\pm$ 22
<i>p</i> -value		<b>0.036</b>
Cohen's <i>d</i>		0.19

Note: Significant *p*-values and large effect sizes ( $> 0.8$ ) reflecting training effects are denoted in bold.

voluntarily to participate in the study and signed an informed consent.

## Results

For all intelligibility measures, the three judges showed an excellent overall interrater reliability (ICC = 0.979,  $p < 0.001$ , 95% confidence interval (CI) = 0.972–0.985). The ICC for the individual tasks ranged from 0.967 to 0.983 with a strong significance ( $p < 0.001$ ).

### *Between-groups (articulatory drill versus minimal pairs) differences*

No significant differences were found between the effects of the two intervention programmes, allowing us to combine the data of both therapy programmes.

### *Effect of articulation therapy on intelligibility in time*

Mixed-models analysis showed a significant increase in the intelligibility after BArT in three speech tasks, namely the NSVO, NSVO-Z and automatic sequences (table 2).

Patients score higher after the intervention, respectively, a mean increase of +6% on both the NSVO

Table 3. Summary of effect sizes by groups of DSLs and time point

	Mild ( $n = 6$ )		Moderate ( $n = 5$ )		Severe ( $n = 6$ )	
	Baseline	Post-measurement	Baseline	Post-measurement	Baseline	Post-measurement
<b>NSVO</b>						
Mean $\pm$ SD	82 $\pm$ 8	90 $\pm$ 5	78 $\pm$ 9	83 $\pm$ 8	58 $\pm$ 11	63 $\pm$ 15
$p$ -value		<b>0.038</b>		0.211		0.197
Corrected $p$ -value		0.114		0.394		0.394
Cohen's $d$		<b>1.36</b>		0.70		0.41
<b>NSVO-Z</b>						
Mean $\pm$ SD	88 $\pm$ 10	95 $\pm$ 3	79 $\pm$ 13	79 $\pm$ 9	42 $\pm$ 19	53 $\pm$ 15
$p$ -value		0.051		0.861		<b>0.005</b>
Corrected $p$ -value		0.102		0.861		<b>0.015</b>
Cohen's $d$		<b>1.06</b>		0.00		0.70
<b>Automatic sequences</b>						
Mean $\pm$ SD	94 $\pm$ 6	98 $\pm$ 2	87 $\pm$ 8	86 $\pm$ 10	53 $\pm$ 19	59 $\pm$ 23
$p$ -value		0.076		0.640		<b>0.016</b>
Corrected $p$ -value		0.152		0.64		<b>0.048</b>
Cohen's $d$		<b>1.09</b>		-0.12		0.32

Notes: <sup>a</sup> Corrected  $p$ -values after the Bonferroni–Holm correction for multiple testing are added after the raw  $p$ -values. Significant  $p$ -values and large effect sizes ( $> 0.8$ ) reflecting training effects are denoted in bold.

( $F(1.16) = 9.129$ ,  $p = 0.008$ ) and the NSVO-Z ( $F(1.16) = 7.977$ ,  $p = 0.012$ ). The two assessments demonstrated a moderate effect size (Cohen's  $d > 0.2$ ) between the baseline and post-measurement. A similar improvement in perceptual intelligibility was found in the scores of automatic sequences ( $F(1.16) = 5.251$ ,  $p = 0.036$ ). An increase of +4% was found after the intervention, but a small effect size (Cohen's  $d < 0.2$ ) was demonstrated in time.

Descriptive results of the other speaking tasks show overall small increments in intelligibility due to the training programme. Nevertheless, no other significant improvements were found in spontaneous speech ( $F(1.16) = 3.632$ ,  $p = 0.075$ ) and in the standard passage ( $F(1.16) = 1.186$ ,  $p = 0.292$ ). Small effect sizes (Cohen's  $d < 0.2$ ) of the intervention were demonstrated in time.

#### Training effects compared by severity levels

When examining the training effects, significant differences ( $p < 0.001$ ) were found per group of dysarthria severity levels (DSLs). A comparison between the three groups, namely mild ( $n = 6$ ), moderate ( $n = 5$ ) and severe dysarthria ( $n = 6$ ) was performed by post-hoc analysis of the mixed models. Table 3 represents the results of the training effects over time divided by DSLs.

The results of the standardized assessment NSVO show a significant difference between DSLs ( $F(2.4) = 14.319$ ,  $p < 0.001$ ). Post-hoc analysis determined a significant increase in time of 8% for the mild group ( $p = 0.038$ ). However, the significant difference was not preserved after correction for multiple testing ( $p = 0.114$ ). Nevertheless, a large effect size was found between the scores of two time points. For moderate and severe groups, descriptive results indicate improvements of +5%; however, no statistically significant results were found. Figure 2 illustrates the evolution of each group of severity levels.

The results of the standardized assessment NSVO-Z also show a significant difference between DSLs ( $F(2.14) = 21.023$ ,  $p < 0.001$ ). The severe group improved significantly over time ( $p = 0.005$ ); even after the Bonferroni–Holm correction, the significance was preserved ( $p = 0.015$ ). A moderate effect size was demonstrated. The mild group improves with +7%; moreover, a large effect size was found between the scores of the measure moments. The moderate group seems to be steady.

For automatic sequences, a significant difference was also found between DSLs ( $F(2.14) = 13.901$ ,  $p < 0.001$ ). The severe group increased significantly over time with +6% ( $p = 0.016$ ); the significance is preserved after correction for multiple testing ( $P = 0.048$ ). The mild group improves with +4% after training

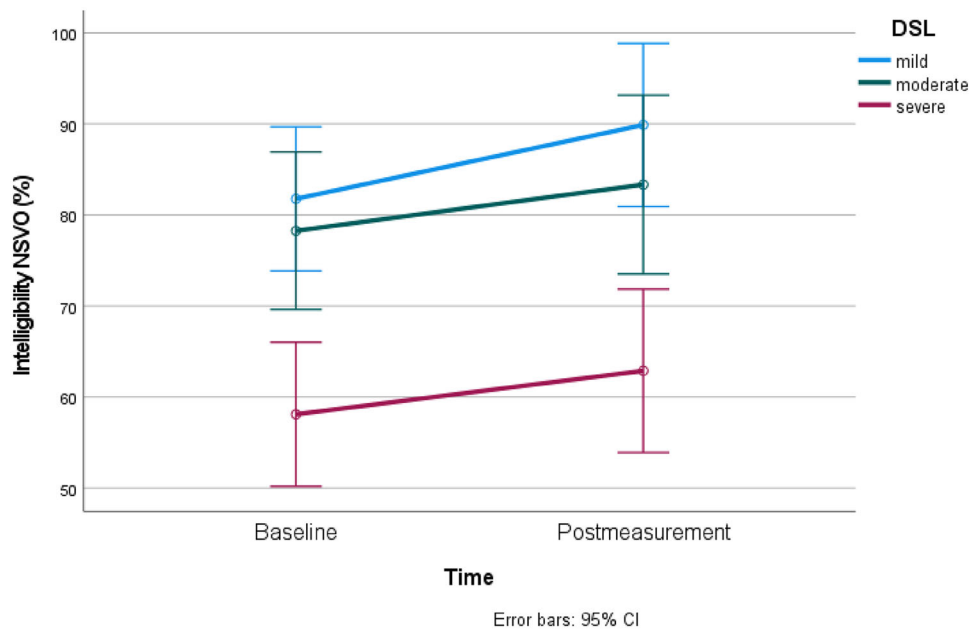


Figure 2. Training effects of the BArT divided by DSLs. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

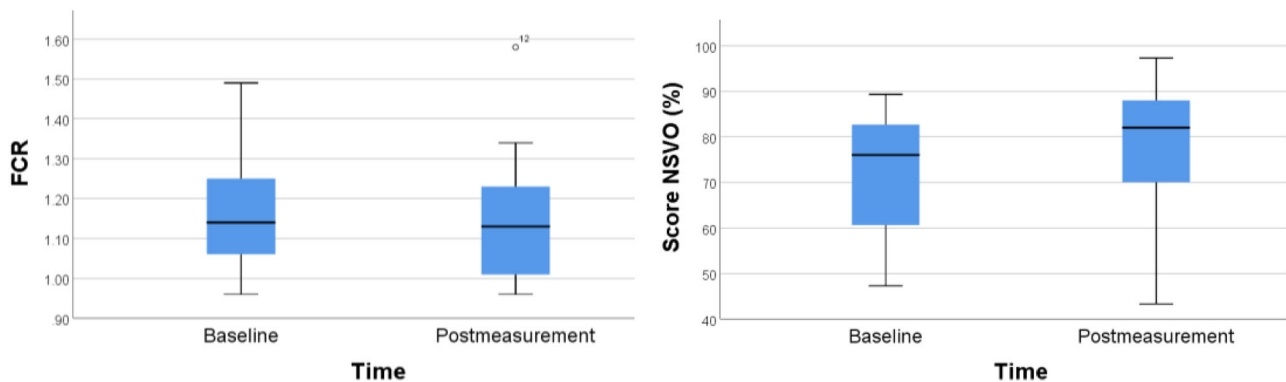


Figure 3. FCR and Intelligibility (NSVO) before and after therapy. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

and a large effect size was demonstrated. The moderate group decreased by  $-1\%$  over time, which is reflected in the negative effect size score.

#### Acoustic analysis

After testing for normality, the Pearson correlation coefficient was calculated in order to verify the relationship between FCR and intelligibility scores, pre- and post-therapy. A negative strong correlation was found for the NSVO ( $r = -0.857$ ,  $p = 0.000$ ). This implies that FCR scored lower in participants where positive changes in intelligibility were observed after BArT. Box plots illustrating the differences of FCR and intelligibility before and after therapy, respectively, are shown in figure 3. Mixed-models analysis did not show a significant difference between pre- and post-treatment values of the FCR; however, individual re-

sults of each subject showed improvements in vowel production.

#### Discussion

The articulatory accuracy of patients with dysarthria is one of the most affected speech dimensions with a high impact on intelligibility (De Bodt *et al.* 2002). Either direct or indirect methods can be used for articulation therapy in the treatment of patients with dysarthria. Although direct articulation therapy is one of the classical ingredients of speech therapy and it has—in contrast with compensatory strategies—the potential to actually improve the underlying impairment in patients with dysarthria, studies investigating its effect on speech intelligibility and its short-term effect are scarce.

To investigate the effect of BArT, implementing the principles of motor learning, two therapy



programmes were designed. The only difference between both programmes is the exercise material with one programme using articulatory drills (BAiT-AD) and the other one using minimal pairs (BAiT-MP). This pilot study shows that a five-day BAiT programme targeting the main distorted phonemes can significantly improve speech intelligibility in patients with dysarthria.

Significant increases of intelligibility were observed for three different speech tasks, at a phoneme level (NSVO), in automatic sequences and even at the sentence level (NSVO-Z). These outcomes are in line with the results of Hartman *et al.* (1979) and Marchant *et al.* (2008), showing that there is an improvement in the trained tasks. However, the former two studies are only a case report of longer treatment programmes. The results of our study demonstrated that intensive treatments focusing on the segmental level of speech succeed to elicit improvements in speech intelligibility at different levels in a short period of time. This shows that patients with chronic or progressive dysarthria can continue exploiting and developing all available residual motor skills.

The perceptual assessments are supported objectively by the results of the acoustic analysis, which revealed a reduction in FCR scores after BAiT where significant improvements of intelligibility were observed. Although no statistically significant differences were found for FCR values pre- and post-treatment, the results show a positive tendency. The FCR analyses the formant frequencies of vowel articulation, while perceptual evaluation of intelligibility includes a more extensive range of parameters and focuses on both consonant and vowel production. FCR values are well correlated with intelligibility in this study. The acoustic analysis documents the therapeutic effect of the BAiT in the expansion of the vowel space. The lower values of FCR obtained in this study are the result of a wider range of articulatory movements and more precise positions of the articulators during speech. Perceived improvements in speech production due to the treatment effects are reflected in the vowel expansion toward normalcy (decreased FCR).

No significant improvements in overall intelligibility were found in spontaneous speech and the standard passage. These findings are comparable with similar studies that also aim to improve intelligibility (Pennington *et al.* 2006, Lowit *et al.* 2020) by applying different intervention methods, without any significant improvements in those specific speaking tasks. Nevertheless, the descriptive analysis showed that small but not significant gains were achieved due to the training programme for those speaking tasks. This suggests that it is important to continue with the intervention for a longer period of time. In some cases, additional prac-

tice/techniques at the suprasegmental level for those linguistic levels might be also recommended. Previous research into motor skills clearly shows that an exercise schedule in which constant exercise is followed by variable exercise seems to be optimal (Maas 2015). Adding variability of practising will lead to better performances on effective re-learning, retention and generalization of trained motor skills. Obviously, BAiT-MP has a higher degree of variability due to the elicited contrasts while drill exercises are generally considered to be constant in nature. However, as the phonetical context (preceding or succeeding phoneme) of the target phoneme changes all the time and as section 3 consists of utterances with the target phoneme in different, mixed positions, also BAiT-AD implies some degree of variability. This might contribute to the lack of a significant difference in intelligibility following BAiT-MP and BAiT-AD.

After careful analysis, not any remarkable difference was found in the effects of the applied articulation training programmes on the different types of dysarthria. Intelligibility improves for the majority of subjects regardless of the type of dysarthria, aetiology, severity, age, and also despite the therapy programme they followed (BAiT-AD or BAiT-MP). Both approaches had comparable results in the impact they have on intelligibility.

The lack of between-subjects' differences in outcome might be due to the small sample size, but might also be due to the fact that BAiT uses a patient-specific error analysis and therefore a patient-specific target sound selection. Although articulation difficulties occur in all types of dysarthria, it has also been shown that the type of articulatory errors and more precisely the type of distortions depends upon the underlying pathomechanism (Antolik 2013). By using a patient-tailored method, the possible effects of BAiT can be equalized for all subjects, regardless of the underlying aetiology.

A positive effect of BAiT was found in each severity group for phoneme intelligibility (NSVO), sentence intelligibility (NSVO-Z) and automatic sequences. Due to the small sample sizes of these subgroups, the improvements do not reach the level of significance; however, large or moderate positive effect sizes were demonstrated. These results suggest that even adults with moderate to severe chronic or progressive dysarthria may benefit from BAiT, which is of high clinical interest as the focus on direct articulation therapy often shifts to compensation in this population (Miller and Bloch 2017). Future research needs to confirm this effect and to determine if this improvement is reflected in the patient's daily communication.

To support the recovery of disordered speech motor execution, an extensive, well-structured and hierarchical practice package of exercises is recommended. Standardized, well-structured therapy programmes for direct

articulation therapy are lacking. The two programmes developed for this study seem to be feasible and well-tolerated by the patients. Therefore, the structure can be used in further clinical practice and research.

### Limitations

A generalization of these results has to be done with care because the study was restricted to the short-term evolution in a rather small group. Also, there is no control group without speech training to exclude spontaneous changes and order effects of repeated testing. Post-treatment reassessment of the SHI was not collected because the period for re-examination was too short for a questionnaire of this type.

### Future research

Future research will focus on the mid- and long-term global effects of the BAiT and the possible differences between BAiT-MP and BAiT-AD in a larger population. Evaluation of the effects on daily communication has also to be investigated as well as the generalization of this therapy to other levels of speech. The use of a control treatment (e.g., traditional or standard methods of dysarthria therapy) to determine whether the effects of the intervention in this population are treatment specific also warrants investigation. Besides the cost-efficacy of the intervention has to be also analysed and compared with other treatments.

### Conclusions

The results of the current study demonstrated that a five session-BAiT significantly improves speech intelligibility and reduces impairment in chronic or progressive mild to severe dysarthria.

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### Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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