

RESEARCH REPORT

Speech treatment for Hebrew-speaking adolescents and young adults with developmental dysarthria: A comparison of *mSIT* and Beataalk

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Email: micallec@ariel.ac.il**Abstract**

Background: Individuals with developmental dysarthria typically demonstrate reduced functioning of one or more of the speech subsystems, which negatively impacts speech intelligibility and communication within social contexts. A few treatment approaches are available for improving speech production and intelligibility among individuals with developmental dysarthria. However, these approaches have only limited application and research findings among adolescents and young adults.

Aims: To determine and compare the effectiveness of two treatment approaches, the *modified* Speech Intelligibility Treatment (*mSIT*) and the Beataalk technique, on speech production and intelligibility among Hebrew-speaking adolescents and young adults with developmental dysarthria.

Methods & Procedures: Two matched groups of adolescents and young adults with developmental dysarthria participated in the study. Each received one of the two treatments, *mSIT* or Beataalk, over the course of 9 weeks. Measures of speech intelligibility, articulatory accuracy, voice and vowel acoustics were assessed both pre- and post-treatment.

Outcomes & Results: Both the *mSIT* and Beataalk groups demonstrated gains in at least some of the outcome measures. Participants in the *mSIT* group exhibited improvement in speech intelligibility and voice measures, while participants in the Beataalk group demonstrated increased articulatory accuracy and gains in voice measures from pre- to post-treatment. Significant increases were noted post-treatment for first formant values for select vowels.

Conclusions & Implications: Results of this preliminary study are promising for both treatment approaches. The differentiated results indicate their distinct application to speech intelligibility deficits. The current findings also hold clinical significance for treatment among adolescents and young adults with motor speech disorders and application for a language other than English.

KEYWORDSBeataalk, developmental dysarthria, *mSIT*, speech intelligibility, speech treatment

What this paper adds

What is already known on the subject

- Developmental dysarthria (e.g., secondary to cerebral palsy) is a motor speech disorder that negatively impacts speech intelligibility, and thus communication participation. Select treatment approaches are available with the aim of improving speech intelligibility in individuals with developmental dysarthria; however, these approaches are limited in number and have only seldomly been applied specifically to adolescents and young adults.

What this paper adds to existing knowledge

- The current study presents preliminary data regarding two treatment approaches, the *mSIT* and Beataalk technique, administered to Hebrew-speaking adolescents and young adults with developmental dysarthria in a group setting. Results demonstrate the initial effectiveness of the treatment approaches, with different gains noted for each approach across speech and voice domains.

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

- The findings add to the existing literature on potential treatment approaches aiming to improve speech production and intelligibility among individuals with developmental dysarthria. The presented approaches also show promise for group-based treatments as well as the potential for improvement among adolescents and young adults with motor speech disorders.

INTRODUCTION

‘Dysarthria’ is a general term for a group of motor-based speech disorders in which impaired functioning is noted in one or more of the speech subsystems (respiration, phonation, articulation, resonance and prosody), resulting in reduced speech intelligibility (Duffy, 2013). Many individuals with developmental dysarthria, commonly associated with cerebral palsy (CP) (Mei et al., 2014), demonstrate intelligibility deficits that continue from childhood into adolescence and adulthood (Carl & Icht, 2021; Lee et al., 2014; Platt et al., 1980). These impairments negatively affect daily functioning and participation within social and communicative contexts (Mei et al., 2014). As such, the implementation of effective treatment for intelligibility deficits among individuals with developmental dysarthria is of paramount importance. The goal of the current study was to determine the effectiveness of two speech intelligibility treatment approaches, the *modified* Speech Intelligibility Treatment (*mSIT*; based on Levy et al. (2021) and the Beat-

alk technique (Icht, 2019), among Hebrew-speaking adolescents with developmental dysarthria, and to compare the benefits of each.

SPEECH PRODUCTION IN CEREBRAL PALSY

Individuals with developmental dysarthria secondary to CP demonstrate speech intelligibility deficits on different linguistic levels (Allison & Hustad, 2018; Chen et al., 2018), with varying contributions of the speech subsystems (Hustad et al., 2010). Respiratory and phonatory deficits may include reduced respiratory control, difficulty with coordination of respiration and phonation (Pennington et al., 2018), reduced vocal intensity (Allison & Hustad, 2018), reduced vocal quality, and impaired variation and control of fundamental frequency (Pennington et al., 2010a; Schölderle et al., 2016). Resonance and prosodic impairment have also been documented among individ-

uals with CP, characterized by hyper- or hypo-nasality (Schölderle et al., 2016), as well as reduced speech rate and impaired intonational patterns (Allison & Hustad, 2018; Kuschmann et al., 2017), respectively. Articulatory deficits are typically characterized by impaired production of both consonants (Allison & Hustad, 2018; Ansel & Kent, 1992) and vowels (Higgins & Hodge, 2002; Levy et al., 2016). Specifically, several consonantal errors have been documented as contributing to the intelligibility deficit, including voicing errors (Nordberg et al., 2014), weak stop consonant production (Allison & Hustad, 2018) and difficulty with the fricative–affricate consonant contrast (Ansel & Kent, 1992). Furthermore, reduced acoustic vowel space (e.g., Higgins & Hodge, 2002) and shallow second formant slopes (Lee et al., 2014) are typical of the acoustic profiles of individuals with CP, indicating articulatory undershoot and/or imprecision (Allison & Hustad, 2018; Allison et al., 2017; Kent & Kim, 2003). Vowel acoustic measures have been correlated with speech intelligibility among children and young adults with CP, across languages, including English (Higgins & Hodge, 2002), Mandarin (Chen et al., 2018) and Hebrew (Carl & Icht, 2021). The articulatory deficits form a primary contribution to reduced intelligibility on the word and sentence levels (Chen et al., 2018; Lee et al., 2014) and necessitate relevant treatment approaches, as described next.

SPEECH TREATMENTS FOR DEVELOPMENTAL DYSARTHRIA

Several treatment approaches have been offered to address speech and intelligibility deficits among individuals with developmental dysarthria (for a summary, see Table 1). One such treatment is the *speech systems* approach (e.g., Pennington et al., 2006, 2010). This approach targets improved functioning of several speech subsystems (e.g., phonation, respiration, prosody), without directly targeting articulatory skills. It is based on the notion that speech sound production and overall intelligibility are impacted by impaired functioning at the levels of the respiration, phonation and prosody (Pennington et al., 2010a). In this treatment, participants focused on the stabilization of respiration, phonation and speech rate at various linguistic levels. Positive gains in speech intelligibility have been reported following treatment in both younger children (Pennington et al., 2013) and older children (Pennington et al., 2010a) with CP. However, a possible limitation of this treatment approach is its use of multiple instructions, a potential confounding factor in light of the comorbid language-learning deficits commonly noted in individuals with CP (Beckung & Hagberg, 2002).

The Lee Silverman Voice Treatment (LSVT) LOUD (Ramig et al., 1995) is an additional treatment approach applied to individuals with developmental dysarthria. Originally implemented among adults with dysarthria secondary to Parkinson's disease, this *global* treatment (Fox et al., 2006) makes use of a single verbal cue ('speak loud') to encourage healthy vocal loudness at varying linguistic levels (sustained vowels, words, connected speech). Increasing vocal intensity not only increases audibility, but also brings about benefits across the speech production system, including improved vocal quality, articulation and intelligibility (Dromey et al., 1995; Levy et al., 2020a; Sapir et al., 2007). These benefits have also been demonstrated in its application to children with CP (Bolie & Fox, 2017). LSVT LOUD follows a prescribed, intense treatment schedule (four times weekly, for 4 weeks), a factor that may in fact be limiting to potential participants and clinicians due to logistics and time constraints.

The current study focuses on two additional treatment approaches, SIT and Beataalk, which are described below in more detail.

Speech Intelligibility Treatment (SIT) (Levy et al., 2021)

Similar to LSVT LOUD, this approach also involves the use of global cues for the treatment of intelligibility deficits among children with developmental dysarthria. Designed for children with CP, SIT is a *dual-focus approach* (Levy et al., 2017, 2021; Moya-Galé et al., 2021b) in which both speech loudness and articulatory excursions are targeted. On the one hand, it aims for the benefits of increasing vocal intensity through the 'strong voice' instruction, as detailed above (see LSVT LOUD). On the other hand, SIT also promotes hyper-articulation through the 'big mouth' instruction, and thus aims for the increased vowel space and intelligibility that characterize clear speech (Ferguson & Kewley-Port, 2002; Park et al., 2016; Perkell et al., 2002). The SIT approach includes both individual and group sessions, and uses an intense camp-like treatment schedule, consisting of 6.5 h of treatment daily, 5 days per week, for a total of 3 weeks. Recent evidence has demonstrated the efficacy of this treatment protocol on the intelligibility of connected speech (within narrative production) in both English- (Levy et al., 2021) and French-speaking children with CP (Moya-Galé et al., 2021b).

The SIT approach is guided by a principle of neuroplasticity, namely the use of simple cues to effect change in more complex movements (Fox et al., 2006). Following this principle, the SIT cues ('big mouth, strong voice') are simple and direct, and thus easy to comprehend and

TABLE 1 Comparison of treatment approaches for developmental dysarthria: Primary characteristics

	Speech systems approach (2010a)	LSVT LOUD (Boliek & Fox, 2014)^a	Speech Intelligibility Treatment (SIT) (Levy et al., 2021)	Modified Speech Intelligibility Treatment (mSIT)^b	Beataalk (Icht, 2021)^b
Principle/purpose	Control of breath support, phonation and speech rate	Increased vocal intensity	Increased speech intelligibility	Increased speech intelligibility	Increased articulatory accuracy
Principles of neuroplasticity or motor learning	Intensity (practice), random practice, decreasing feedback, knowledge of results and performance	Intensity (dosage, practice); specificity, task complexity; motivation	Salience of task; intensity (dosage; practice); decreasing feedback	Salience of task; intensity (practice); decreasing feedback	Intensity (practice); random practice; complexity of targets
Dosage (Setting)	Three 45-min sessions per week for 6 weeks (individual)	Four 1 h sessions per week for 4 weeks (individual)	6.5 h/day for 5 days, across 3 weeks; 'camp-like' setting (individual and group)	Once per week for 9 weeks (group)	Once per week for 9 weeks (group)
Treatment activities and stimuli	Sustained vowels, functional phrases, novel phrases (single words, sentences, conversation)	Sustained phonation, pitch changes, functional phrases, structured reading, conversational speech	Activities designed to elicit speech; included barrier tasks, minimal pair vowel tasks, functional sentences	Activities designed to elicit speech; included barrier tasks, minimal pair vowel tasks, functional sentences	Repetitions of human beatboxing speech-like sounds (syllable level), within musical contexts (different rhythms)
Instructions	Practice coordination of respiration and phonation during speech tasks; speaking slowly with adequate breath supply	'Speak loud'	'Speak with your big mouth; speak with your strong voice'	'Speak with your big mouth; speak with your strong voice' (adapted to Hebrew)	Modeling and imitation; simple instructions pertaining to accuracy and speed

Note: ^aLSVT LOUD was originally designed for and implemented among individuals with Parkinson disease (e.g., Ramig et al., 1995).

^bAs presented in the current study; changes to treatment design may be applied in future studies, given the novelty and development of these approaches.

implement, aiming for maximal impact on multiple speech subsystems. In studies investigating the effects of these cues on acoustic and perceptual characteristics of speech among children with CP (*not* in the context of treatment), Levy et al. demonstrated gains in vocal loudness, and, generally, reductions in speech rate, in both English (Levy et al., 2017) and French (Levy et al., 2020b).

The speech cues in SIT are provided within various activities that are designed to enhance functional gains in speech intelligibility within the intervention (Levy et al., 2021). These tasks include production of functional sentences, vowel contrasts and barrier games within speech contexts of increasing linguistic complexity. The treatment protocol also considers the principles of motor learning (PML; Maas et al., 2008), with intensity of practice and decreasing feedback implemented (Edeal & Gildersleeve-Neumann, 2011; Maas et al., 2012). In the current study, a modified version of the SIT (*mSIT*) was implemented, with

adjustment primarily to the treatment schedule (less intensive) and format (group setting).

Beataalk

Recently applied to the treatment of developmental speech impairment, the Beataalk technique (Icht, 2019) uses the musical vocal art of beatboxing to target production of speech sounds, primarily consonants. Within this technique, participants produce speech-like sounds (e.g., the *kick drum*: /p/, the *snare drum* /k/) in the context of rhythmic productions. Icht (2019) demonstrated greater gains in articulation accuracy and voice measures following treatment using the Beataalk technique among adults with intellectual disability and reduced speech intelligibility, in comparison with those who received traditional articulation therapy. Emerging evidence of improved speech sound

production is also reported among adults with CP following this treatment approach (Icht, 2021).

The Beataalk technique has theoretical underpinnings in several disciplines in its potential application to treatment of developmental dysarthria. First, the use of beatboxing involves not only the articulatory system; rather, it requires the use of multiple speech subsystems (e.g., respiration, resonance) for the production of the speech-like sounds (De Torcy et al., 2014). Human beatboxing involves control of the oral cavity and oropharyngeal structures (pharyngeal constrictors), resulting in a longer closed phase of vocal fold vibratory cycle and increased subglottal pressure (Buescher & Sims, 2011). This may positively influence vocal loudness and vocal quality. Considering the deficits of multiple subsystems in developmental dysarthria, engaging mechanisms of increased respiratory support and vocal quality through beatboxing could have a positive impact on speech intelligibility. A second benefit is reflected in the characteristics of speech sound impairment and contrast errors in developmental dysarthria. Speech sounds involving respiratory support (e.g., production of stop bursts; Allison & Hustad, 2018) and fricative–affricate contrasts (Ansel & Kent, 1992) are notably impaired in this population, and contribute to reduced intelligibility among speakers with CP. Thus, targeting these sounds in treatment (as targeted in the Beataalk approach) may positively affect speech intelligibility. Finally, the high intensity practice and repetitions, which are central to beatboxing, may encourage production consistency, thus improving motor learning and speech motor control (Ludlow et al., 2008; Maas et al., 2008).

THE CURRENT STUDY

The goal of the current study was to determine the effects of two treatment approaches, a modified version of SIT (*mSIT*) and Beataalk, on the speech production and intelligibility of Hebrew-speaking adolescents with developmental dysarthria, and to compare the two approaches. This may have an important clinical contribution due to the relative lack of research focusing on therapy outcomes in this age group. In light of the above-mentioned literature review, we expected gains in at least some of the tested measures across both treatments. More specifically, given the global focus of the SIT approach on overall speech production, gains for *mSIT* were expected in both speech intelligibility and voice measures. With the focus of the Beataalk treatment on rapid and intense consonant production and controlled breathing patterns, gains were anticipated in articulatory and voice measures, which may also positively affect speech intelligibility. It should be noted that speech intelligibility is influenced by various factors, among them

articulation, phonatory, resonance and prosody characteristics (Kent et al., 1994; Miller, 2013). Although not all these aspects were directly targeted in the current treatments, improvement of speech intelligibility was expected, at least to some degree, in both groups.

METHODS

Participants

The study was approved by the Ariel University ethics committee. The parents or legal guardians of the participants received written information regarding the study, and all gave their written consent. All participants were given verbal information on the study and its goals and consented verbally.

The study was conducted in a rehabilitative educational centre for children and adolescents with CP and complex disabilities in Tel Aviv, Israel. A total of 17 adolescents with developmental dysarthria, secondary to CP and other motor disabilities (15–20 years, mean = 17, SD = 1.58) participated in the treatments. Recruitment was conducted by the educational and therapeutic staff at the centre, based on the following inclusion criteria: (1) a diagnosis of developmental dysarthria (as recorded in existing medical and educational files); (2) intact cognitive abilities (as per medical records); (3) speech as the primary means of communication; (4) normal or corrected to normal hearing; and (5) proficiency in Hebrew.

Participants were assigned to either treatment group, *mSIT* ($n = 8$) or Beataalk ($n = 9$) by the educational staff, in light of practical (scheduling) factors, while ensuring that the groups were equal with regard to age, $t(15) = 0.92$, $p = 0.375$, and severity of the speech disorder. Severity was confirmed by comparable pre-treatment intelligibility scores, $t(15) = 0.33$, $p = 0.75$. Participant data for both treatment groups are listed in Table 2 (participant data were also reported previously by Carl & Icht (2021)). A review of these data demonstrates that the groups were not matched with regard to gender; however, the literature indicates that this factor may not be associated with intelligibility deficits (Whitehill & Ciocca, 2000).

It should be noted that two participants, one from each group (no. 2 from the *mSIT* group and no. 1 from the Beataalk group) (Table 2) were excluded from the final analyses due to absence from multiple treatment sessions, resulting in a final sample of 15 participants.

Procedures and experimental design

The study was implemented in a group pre- to post-treatment research design (as in Icht, 2019; Levy et al., 2013;

TABLE 2 Participant data for each treatment group. Single-word intelligibility scores were obtained from pre-treatment assessment data

No.	Age (years; months)	Gender	Aetiology and associated conditions	Perceptual speech characteristics	Single word intelligibility (%)
<i>Treatment group: mSIT</i>					
1	20;11	Female	Cerebral palsy (CP), spastic quadriplegia, neuromuscular scoliosis	Imprecise articulation, limited pitch control	13%
2	20;1	Male	CP	Reduced intelligibility, pitch deficits	47%
3	16;9	Female	CP, epilepsy, left hemiplegia	Hoarse voice	50.5%
4	18	Female	CP, quadriplegia, hypotonia	Imprecise articulation, speech coordination deficits	57%
5	16;5	Female	Encephalopathy due to BI deficiency	Hoarse voice, reduced speech rate	64%
6	17	Male	Methylglutaconic aciduria type III-3, cortical vision impairment, motor problems	Imprecise articulation, speech coordination deficits	82%
7	15;9	Female	CP, spastic diplegia (right)	Reduced speech rate, hypernasality, high pitch	88%
8	18	Female	CP	Hoarse voice, poor respiratory support	92%
<i>Treatment group: BeataTalk</i>					
1	18;9	Male	CP	Reduced intelligibility, reduced speech rate	3%
2	17;6	Female	CP, spastic diplegia, athetoid movements	Imprecise articulation, irregular speech rate and stress patterns	15%
3	16;2	Male	CP, spastic quadriplegia, cortical vision impairment	Multi-subsystem deficits, respiratory coordination difficulties	45%
4	16;1	Male	CP	Stuttering, coordination difficulties	54%
5	16;9	Male	CP, spastic diplegia, epilepsy	Stuttering	73.5%

(Continues)

TABLE 2 (Continued)

No.	Age (years; months)	Gender	Aetiology and associated conditions	Perceptual speech characteristics	Single word intelligibility (%)
6	19;7	Male	CP	Mono-pitch, imprecise articulation, coordination difficulty, perseverations	74.5%
7	15;4	Female	Idiopathic developmental motor delay, vision impairment, learning disability	Reduced vocal intensity	79%
8	16;9	Male	CP	Mono-pitch, voicing and pitch control deficits	81%
9	18;9	Female	CP, epilepsy, attention-deficit/hyperactivity disorder	Voicing deficits	89.5%

Moya-Galé et al., 2021b). All assessment and treatment procedures were conducted at the educational rehabilitative centre by speech and language therapy graduate research assistants fully trained in each of the treatment approaches by the first and third authors. This training was conducted prior to the treatment, using video tutorials and in-person meetings. In order to maintain fidelity of assessment and treatment as well as to ensure high-intensity and continuous practice within treatment sessions, consistent supervision was provided by the first author across sessions. Assessment sessions were individual and consisted of recording participants during a variety of speech tasks, both before and immediately following treatment. The treatment schedule was identical for both approaches and consisted of a total of nine weekly sessions each of 45 min. This schedule was dictated by the educational centre due to logistical considerations. Two staff speech language pathologists (SLPs) from the centre who were familiar to the participants were also present during the treatment sessions, in order to ensure participation and individual practice. Due to the inability to monitor and track practice outside of the group treatment sessions, home training was not formally instructed.

Treatment protocol

mSIT

The implementation of the *mSIT* protocol in the current study adhered to the *SIT* protocol to the extent possible, as described above, but also necessitated certain modifications. First, due to practical considerations and time constraints, treatment was provided only once weekly, in 45-min sessions, for a total of 9 weeks. Second, the difference in treatment schedule required that the therapeutic speech tasks (functional sentences, vowel contrast tasks, barrier games) all be targeted within the single, weekly session. Third, due to the nature of the Hebrew vowel system (five vowels: /a/, /i/, /o/, /u/, /e/), vowel contrasts were limited in nature (e.g., /o/ versus /u/, /e/ versus /i/), and consisted of fewer minimal contrasts than are found in American English. Finally, all therapeutic sessions were conducted in a group format; to address this adaptation with respect to intensity of practice, the multiple staff members present during the treatment sessions ensured that each participant within the group produced and continuously practiced the targeted speech tasks with a high level of intensity.

The activities in the current protocol were designed to be engaging and fun, age appropriate (for adolescents and young adults), and to elicit speech with multiple repetitions and practice within each treatment session. The

first three weekly treatment sessions elicited speech on the word level, the following three on the sentence level, and the final three treatment sessions elicited conversational speech and/or speech intended for generalization to new contexts. The speech cues were translated from English (/lədabeɪ bəkɒl, ɪm pɛ ɡadɒl/; translated generally as ‘speak loudly, with a big mouth’) and feedback regarding the elicited speech was faded gradually over the course of the treatment.

Beatalk

The Beatalk treatment followed the protocol detailed in Icht (2019). Targeted stimuli consisted of speech-like beatboxing sounds, specifically /t/, /ts/, /p/, /pf/, /k/, and /kf/. In each treatment session, target sounds were chosen for practice and were elicited both in isolation and in simple rhythms (e.g., /p-p/), as well as increasingly complex sequences: /p-ts, p-ts/, /p-p-ts/, /p-t-kf, p-t-kf/. (For a demonstration of a typical treatment activity, see <https://www.youtube.com/watch?v=HkmZkAciyaM&t=161s>.) The first 10 min consisted of practising the sounds and sequences from the previous session, followed by 25 min of practising new sounds and sequences, with the last 10 min reserved for practising target rhythms together with a familiar song. This type of practice ensured multiple repetitions of target sounds and sound combinations, especially given the fast tempo of the popular music used in the treatment (dozens of beats per min). In order to engage the participants, individual practice alternated with group practice in the form of a ‘band,’ in which subgroups of participants produced different sounds interchangeably. The multiple staff members present (research assistants and staff SLPs) ensured these high levels of practice among participants. Cueing was provided as needed for accurate production of the target sound (e.g., ‘press your lips together’), and visual cues in the form of orthographic letters and the associated instrument (e.g., ‘p’; kickdrum) were presented in each session; tactile cues were not provided.

Tools and materials

In order to determine effects of treatment in relation to improved subsystem functioning and speech intelligibility, several dependent measures were collected and analysed. These measures were recorded during a variety of speech tasks in the assessment sessions (pre- and post-treatment), using a high-quality digital recorder (Philips DVT4010 audio recorder). Following Carl & Icht, 2021, the recorder was held approximately 8 cm from the partici-

pant’s mouth, with a slight tilt toward the participant. The distance between the recorder and the participant’s mouth was maintained during the recording.

Speech tasks included sustained phonation of the vowel /a/, as well as production of both single words and sentence stimuli. Word stimuli were taken from the Hebrew Articulation and Naming Test (Rosin & Yakir, 2000), which includes 32 common Hebrew words, presented in pictures. An additional six words were added to ensure representation of corner vowels for the acoustic analysis, for a total of 38 words. Sentence stimuli were recorded during a picture description task, in which participants were presented a detailed line drawing depicting a beach scene and were asked to describe what they saw. The speech tasks were identical across assessment sessions (pre- and post-treatment), and each session lasted approximately 20–30 min.

Dependent measures and analysis

Given the complex nature of developmental dysarthria and its variable manifestation on the speech subsystems among different speakers, a wide-range of outcome measures were included. This selection was also influenced by the novelty of the applied treatment approaches, allowing for detection of treatment effects in various speech subsystems. The chosen measures follow those recorded in previous intervention studies, including measures of voice quality (Miller et al., 2014; Pennington et al., 2018), articulation (Icht, 2021), speech intelligibility (Levy et al., 2021; Pennington et al., 2013) and vowel acoustics (Langlois et al., 2020; Levy et al., 2021).

Speech intelligibility

- **Single-word intelligibility:** Words from the Hebrew articulation test, detailed above, were orthographically transcribed by naïve listeners, given no information regarding the speaker and blinded to the purpose of the study. This wordlist was used for both pre- and post-treatment intelligibility judgments. Each speaker’s productions were judged by two independent listeners, as follows: A group of 34 listeners, 26 females and eight males (mean age = 29 years, SD = 6.98, age range = 18–50) rated the pre-treatment data, and another group of 30 listeners, 26 females and four males (mean age = 27 years, SD = 7.2, age range = 18–45) rated the post-treatment data. All listeners reported no hearing impairment and their native language to be Hebrew. Transcriptions were conducted using a designated online platform, in which listeners heard the target word and

were asked to type what they heard. Stimuli were not amplitude normalized prior to listener presentation and listening environment was controlled by instruction to sit in a quiet room and adjust the volume to a comfortable listening level. Listeners were also given a practice listening trial, so that volume adjustments could be made prior to listening to the speaker recordings. For a detailed description of the procedures, see Carl and Icht (2021). The number of correctly transcribed words was divided by the total number of words (38), to yield a single score (%) of intelligibility. Scores from the two listeners were averaged for the final score used for analysis.

- Ease of understanding (EoU): This measure included judgments of sentence stimuli, taken from the picture description task. Four experienced listeners, SLPs with more than 5 years of experience in the field, blinded to the time of assessment and group assignment, listened to all the sentences. Sentence stimuli were judged for ease of understanding on a five-point scale (1 = very difficult to understand, 5 = very easy to understand). No additional training or rating instruction was provided to the experienced listeners.

Articulation accuracy

Percentage of consonants correct (PCC; %): The percentage of consonants produced correctly was taken from single word stimuli, and was analysed in a two-phase process, in light of the subjective nature of consonant assessment using the PCC measure (Shriberg et al., 1997). As a first step, the graduate research assistants transcribed and calculated the PCC for all single word stimuli. Subsequently, an outside judge, an experienced SLP blinded to the purpose of the study and to the assessment time (pre-versus post-treatment), re-analysed consonant production for all participants. Pearson product-moment correlations between the original and re-analysed data revealed high correlation coefficients, $r = 0.93$, $p < 0.001$. To further ensure agreement for individual participant's PCC scores, the absolute difference between raters was calculated for all recordings within each treatment group. If the difference between raters was greater than 2 SDs from the mean absolute difference (less than 25% of all recordings), the associated scores of each were averaged together to yield the final score for that participant.

Voice measures

To evaluate changes in respiratory control and phonatory (vocal) function, various voice measures were chosen. All

measures were taken from the sustained production of the vowel /a/ and analysed in Praat (Boersma & Weenink, 2019):

Maximum phonation time (MPT; s): the maximum length of the sustained vowel /a/ after a maximum inhalation. Increased MPT may indicate improved function of the respiratory and phonatory mechanisms (Icht, 2021).

Jitter (%): cycle-to-cycle variation of the fundamental frequency (F0). Smaller jitter values are associated with greater stability of the vocal fold vibration (Maryn et al., 2009).

Shimmer (%): cycle-to-cycle variation in amplitude of the acoustic signal. Smaller shimmer values represent increased stability of voice quality (Icht, 2019).

It should be noted that although the recorder-to-mouth distance was maintained during the recording of assessment procedures, slight involuntary movements naturally occurred for several participants. As such, intensity was not included as a dependent measure, given its sensitivity to even slight changes in the recording distance (Icht et al., 2021; Švec & Granqvist, 2018). Due to a technical problem with recording, voice data were not available for one participant in the BeataTalk group (participant 8).

Vowel acoustic measures

Further analysis of the articulatory subsystem was conducted by means of vowel acoustic measures. Specifically, a larger vowel acoustic space, as indicated by measures of vowel space area and centralization, has been associated with a greater degree of acoustic vowel separation and improved speech intelligibility (Chen et al., 2018).

Vowel acoustic measures were calculated from first and second formants (F1, F2) of corner vowels /a/, /i/, and /u/, extracted from the midpoint of vowels produced within common Hebrew words, taken from the Hebrew Articulation and Naming test (Rosin & Yakir, 2000). Vowel formant extraction was conducted using Praat (Boersma & Weenink, 2019). Target vowels were produced within single-syllable words or the stressed syllable of bi-syllabic words. Formant values were extracted from the midpoint of the vowel (e.g., Kim et al., 2011), using linear predictive coding (LPC) analysis by means of a Praat-coded automated script. The default number of formants used for extraction was set to 5 for most trials. However, in light of the frequent errors of automated LPC analysis for formant estimation (Kent & Vorperian, 2018), LPC-formant trajectories (F1 and F2) were visually inspected for each vowel trial. If discrepancies in these formant trajectories were noted, the maximum number of formants was adjusted to four or six formants on the Praat-coded script, and



TABLE 3 Stimuli for acoustic analysis (phonetic transcription, English translation)

Vowel	Target word ^a
/a/	/dag/ ('fish'), /haʒ/ ('mountain'), /pax/ ('trash can'), /aɡas/ ('pear'), /xultsa/ ('shirt'), /baʒvaz/ ('duck')
/i/	/pil/ ('elephant'), /tik/ ('bag'), /sakin/ ('knife'), /patif/ ('hammer')
/u/	/sus/ ('horse'), /bul/ ('stamp'), /tuf/ ('marker'), /kaduʒ/ ('ball'), /xatul/ ('cat')

Note: ^aEntries shown in bold indicate the accented syllable from which acoustic data were extracted.

values were extracted accordingly. This occurred on approximately 25% of the data. Formant values were normalized (Bark method) prior to calculation of measures and subsequent analysis, in order to ensure comparability in light of speaker-related differences (e.g., male versus female). For the words from which vowels were extracted, see Table 3. For further details of measure calculation, see Carl and Icht (2021: appx B):

- First and second formants (F1, F2): A comparison of vowel formants across all three corner vowels (/a/, /i/, /u/) from pre- to post-treatment was conducted, in order to determine any change in vowel space area (e.g., Levy et al., 2021; Mou et al., 2019).
- Triangular vowel space area (*tVSA*): The area of the acoustic space (F1 × F2) enclosed by the three corner vowels (/a/, /i/, /u/), with formants averaged across multiple repetitions of each vowel. A single *tVSA* was calculated per speaker for each assessment timepoint (pre- and post-treatment). The formula used for calculation was as follows, as in Sapir et al. (2010):

$$tVSA = |(F1/i/ * (F2/a/ - F2/u/) + F1/a/ * (F2/u/ - F2/i/) + F1/u/ * (F2/i/ - F2/a/))/2| \quad (1)$$

Formant centralization ratio (FCR): A measure of acoustic space centralization, expressed as a ratio between select first and second formants of the corner vowels. This measure was originally applied to the speech of individuals with Parkinson's disease (Sapir et al., 2010), and subsequently used with developmental disorders (e.g., (Chen et al., 2018). Similar to the *tVSA*, a single FCR value was calculated per speaker, for each assessment time:

$$FCR = (F2/u/ + F2/a/ + F1/i/ + F1/u/)/ \\ \times (F2/i/ + F1/a/) \quad (2)$$

Statistical analysis

To assess the normality and distribution of the pre-treatment data, the Shapiro–Wilk test of normality was calculated for each of the treatment groups, separately for each outcome measure. Results demonstrated normality for each measure ($p > 0.05$) in both groups. Means (SDs) were calculated for each measure, across treatment groups and assessment times. To calculate the percentage of change from pre- (T1) to post-treatment (T2), the following equation was used:

$$\frac{T2 - T1}{T1} * 100 = \Delta\% \quad (3)$$

To determine statistically significant change from pre- to post-treatment, a series of one-tailed, paired *t*-tests were applied to most dependent measures, including measures of intelligibility, articulation and voice, for each treatment group independently. Corrections for multiple comparisons were not applied to the data, as conducted by Langlois et al. (2020), due to the preliminary (Phase I) nature of the study in which implementing a more liberal tolerance of Type 1 errors is suggested (Robey, 2004). Due to the variety of measures and scales, analyses of variance (ANOVAs) were not fitting for the data.

Acoustic measures of *tVSA* and FCR also used the paired *t*-test to determine change, whereas F1 and F2 values were analysed by linear-mixed effects (LME) models separately by group. In contrast to the single-value paired data (e.g., for each of pre- and post-treatment) of most outcome measures, including measures of voice, articulation, and two vowel acoustic measures (*tVSA* and FCR), vowel formant data (F1 and F2) included multiple trials and were unbalanced with regard to vowel type. Therefore, the LME analysis was applied to the formant data due to its strength in analysing multiple trials and potentially unbalanced data (e.g., number of vowel targets). The LME model was fitted with *Time*Vowel* as fixed effects and *Participant* as a random effect. Post-hoc analysis for LME models was conducted using estimated marginal means in order to determine change post-treatment across each vowel per group. For measures of articulation, voice and intelligibility, Cohen's *D* effect sizes were calculated (Cohen, 1988) in order to determine degree of change post-treatment as well as to allow a means of comparison between the groups. All statistical analyses were completed in R (R Core Team, 2020), with significance level set at $p < 0.05$.

Reliability

Interrater reliability was also conducted for voice measures and acoustic data. For voice measures (jitter,

shimmer, MPT), the first author re-analysed all productions of the vowel /a/ used for analyses, with respect to vowel boundaries. High correlations were found between values from the two raters for jitter, $r = 0.93$, $p < 0.001$, shimmer, $r = 0.9$, $p < 0.001$, and MPT, $r = 0.997$, $p < 0.001$. For acoustic data, a second judge trained in acoustic analysis, re-analysed 20% of all vowel stimuli, with respect to marking of vowel boundaries from the acoustic signal and inspection of LPC formant tracks. Pearson product-moment correlations between the original and re-analysed data revealed high correlation coefficients for both F1 ($r = 0.97$, $p < 0.001$), and F2 ($r = 0.94$, $p < 0.001$) values. The mean absolute difference between raters was 19.95 Hz for F1 values and 61.25 Hz for F2. These results suggest strong interrater reliability.

RESULTS

A summary of pre- to post-treatment results, including means, SDs, test statistics (p -value) and effect sizes (Cohen's D), for intelligibility, articulation and voice measures is reported for each group in Table 4.

Intelligibility

Single word. Participants in the *mSIT* group demonstrated significant gains ($\Delta\% = 10$ improvement) in single-word intelligibility scores from pre- to post-treatment, $t(6) = -2.730$, $p = 0.017$, with a large effect size (Cohen's $D = 1.03$). No gains were noted for participants in the Beataalk group, $t(7) = -0.669$, $p = 0.262$.

Sentences (ease of understanding—EoU). Similar to results of single-word intelligibility, the *mSIT* group demonstrated significant gains in sentence EoU ($\Delta\% = 11$), as measured by experienced listeners, $t(6) = -2.121$, $p = 0.039$. Cohen's D effect sizes reflected these findings, with a large effect size of 0.802. No difference was demonstrated post-treatment for the Beataalk group, $t(7) = -0.239$, $p = 0.409$.

Articulation

PCC: No gains were noted for participants in the *mSIT* group, $t(6) = 0.485$, $p = 0.678$, while significant improvement ($\Delta\% = 11$) was noted for the Beataalk group, $t(7) = -1.986$, $p = 0.044$, with a moderate effect size, Cohen's $D = 0.7$.

The results of these two key outcome measures, speech intelligibility and articulatory accuracy, are presented in Figure 1.

TABLE 4 Results of intelligibility, articulation and voice measures across treatment groups and assessment time (pre- and post-treatment)

Measures	Modified Speech Intelligibility Treatment (<i>mSIT</i>)				Beataalk			
	Assessment time		<i>p</i> -value ^a	Cohen's <i>D</i> ^b	Assessment time		<i>p</i> -value ^a	Cohen's <i>D</i> ^b
	Pre	Post			Pre	Post		
<i>Intelligibility</i>								
Single words (%)	63.79 (27.43)	69.93 (25.76)	0.02 ^a	1.03	63.94 (24.57)	67.27 (24.40)	0.26	–
Ease of understanding: sentences ^c	2.96 (1.15)	3.29 (1.11)	0.04 ^a	0.8	3.31 (0.66)	3.37 (1.16)	0.41	–
<i>Articulation</i>								
Percentage consonants correct (PCC) (%)	77 (9)	75 (14)	0.68	–	70 (21)	78 (14)	0.04 ^a	0.7
<i>Voice</i>								
Jitter (%)	0.73 (0.35)	0.43 (0.16)	0.02 ^a	1.04	1.89 (1.36)	0.79 (0.35)	0.03 ^a	0.84
Shimmer (%)	4.59 (1.76)	3.79 (1.58)	0.11	–	7.65 (4.50)	7.51 (4.71)	0.47	–
Maximum phonation time (s)	3.59 (2.47)	5.07 (2.39)	0.01 ^a	1.17	1.51 (0.86)	1.79 (0.73)	0.07	0.66

Note: ^aStatistically significant difference from pre- to post-treatment ($p < 0.05$).

^b0.2–0.49 = Small effect size; 0.5–0.79 = moderate effect size; and > 0.8 = large effect size (Cohen, 1988).

^cEase of understanding was judged on a scale from 1 (very difficult to understand) to 5 (very easy to understand).

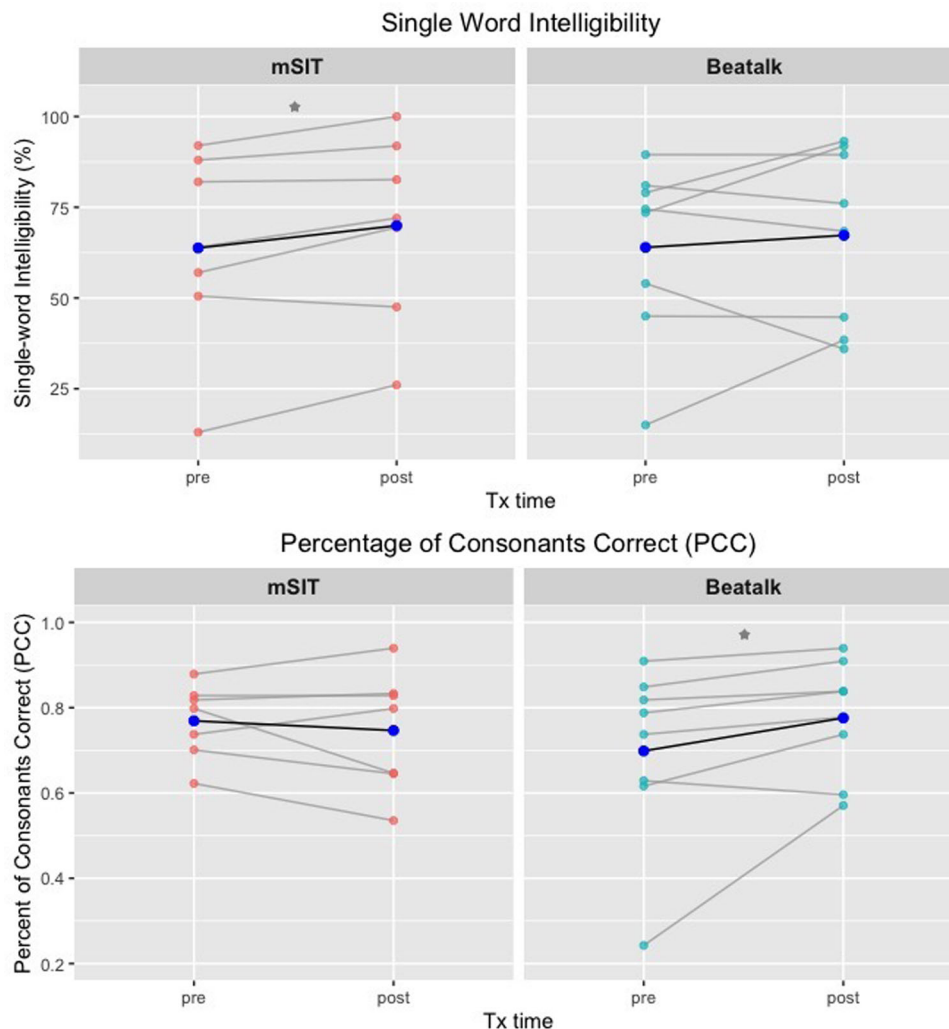


FIGURE 1 Pre- and post-treatment performance for key outcome measures, single-word speech intelligibility and articulatory accuracy (percentage of consonants correct—PCC) for both treatment groups (*mSIT*, *Beataalk*).

Note: Light-coloured lines represent individual participant data; and dark-coloured lines represent group means. *Statistically significant changes from pre- to post-treatment.

[Colour figure can be viewed at wileyonlinelibrary.com]

Voice

Maximum phonation time (MPT): The analysis indicated significant improvement ($\Delta\% = 41$) for the *mSIT* group, $t(6) = -3.104$, $p = 0.011$, and a trend of improvement ($\Delta\% = 18$) for the *Beataalk* group, $t(6) = -1.753$, $p = 0.065$. Effect sizes indicated a greater effect of treatment for the *mSIT* group (large effect, 1.17) than the *Beataalk* group (moderate effect, 0.663).

Jitter: Results revealed significant improvement from pre- to post-treatment for both the *mSIT* group, $t(6) = 2.755$, $p = 0.017$ ($\Delta\% = 41$), and the *Beataalk* group, $t(6) = -2.215$, $p = 0.034$ ($\Delta\% = 58$). Effect sizes (Cohen's *D*) were reported as large for both groups as well: *mSIT* = 1.04, *Beataalk* group = 0.837.

Shimmer: Neither group demonstrated significant improvement for this measure: *mSIT*, $t(6) = 1.35$, $p = 0.113$; *Beataalk*, $t(6) = 0.079$, $p = 0.47$.

Vowel acoustics

A summary of results for vowel acoustic measures is reported for each group in Table 5.

F1: Results of the LME model for the *SIT* group revealed a significant main effect of Time ($\beta = 0.447$, $SE = 0.138$, $t(195) = 3.252$, $p < 0.005$) and Vowel (/i/: $\beta = -2.026$, $SE = 0.154$, $t(195) = -13.179$, $p < 0.001$; /u/: $\beta = -2.008$, $SE = 0.145$, $t(195) = -13.812$, $p < 0.001$). Results for the *Beataalk* group revealed a significant main effect only for Vowel (/i/: $\beta = -2.24$, $SE = 0.167$, $t(225) = -13.375$, $p < 0.001$; /u/: $\beta = -2.249$,

TABLE 5 Means (SDs) of acoustic results, in Bark units, for formant (F1, F2) and vowel space measures for the two treatment groups

Measure	Vowel	Modified Speech Intelligibility Treatment (mSIT)				Beataalk	
		Assessment time		Assessment time		Assessment time	
		Pre	Post	Pre	Post	Pre	Post
F1 (Bark)	/a/	6.78 (0.87)	7.22 (1.04) ^a	6.11 (1.06)	6.23 (0.78)		
	/i/	4.75 (1.12)	4.72 (0.74)	3.87 (0.52)	4.01 (0.71)		
	/u/	4.76 (0.82)	5.04 (0.53) ^a	3.86 (0.57)	4.22 (0.8) ^a		
F2 (Bark)	/a/	11.03 (0.9)	11.26 (0.8)	10.63 (0.93)	10.58 (0.92)		
	/i/	14.11 (0.8)	13.98 (0.94)	13.44 (0.94)	13.32 (1.01)		
	/u/	9.26 (1.3)	9.54 (1.3)	8.44 (0.99)	8.46 (1.3)		
Triangular Vowel space area (Bark)	4.96 (2.1)	5.35 (3.03)	6.09 (3.69)	5.08 (2.19)			
Formant centralization ratio (Bark)	1.43 (0.1)	1.44 (0.09)	1.38 (0.14)	1.4 (0.09)			

Note: ^aStatistically significant change from pre- to post-treatment ($p < 0.05$).

SE = 0.157, $t(225) = -14.309$, $p < 0.001$). Results of post-hoc analyses using estimated marginal means revealed significant differences between pre- and post-treatment for the mSIT group for the vowel /a/, $t(195) = -3.252$, $p = 0.001$ and /u/, $t(195) = -2.009$, $p = 0.046$. The Beataalk group demonstrated a significant difference only for the vowel /u/, $t(225) = -2.17$, $p = 0.031$, from pre- to post-treatment.

F2: Results of the LME model revealed no significant main effect of Time for either of the groups, and post-hoc analyses confirmed that no difference in F2 values were noted between pre- and post-treatment values.

tVSA: No significant difference from pre- to post-treatment for either group, $p > 0.05$.

FCR: Similar to the tVSA measure, no significant results were noted for either group, $p > 0.05$.

DISCUSSION

The current preliminary study investigated the effects of two treatment approaches, the mSIT (based on Levy et al., 2021) and Beataalk technique (Icht, 2019), on various measures of speech production and intelligibility among Hebrew-speaking adolescents with developmental dysarthria. Treatment was implemented in a group setting, for a total of 9 weeks, and outcome measures were assessed prior to and following treatment. Results indicated positive effects of both approaches, with gains noted in at least some of the intelligibility, articulatory, voice, and acoustic measures. More specifically, participants in the mSIT group demonstrated improved speech intelligibility (single word and connected speech), voice characteristics (jitter, MPT), as well as positive changes in formant measures (F1 for vowels /a/ and /u/) from pre- to post-treatment. Participants in the Beataalk group demonstrated improved articulatory skills (PCC), voice characteristics (jitter, MPT), as well as positive changes in formant measures (F1 for /u/). The differences in gains between the two treatments may imply distinct underlying mechanisms and potential benefits, potentially allowing personalized implementation based on recipients' speech profiles.

Intelligibility

Impaired speech intelligibility forms a major barrier to the inclusion of individuals with dysarthria within social and communicative contexts (Mei et al., 2014). Therefore, speech intelligibility is a primary target of intervention programs in this population and was a key outcome measure in the current study. Participants in the mSIT group demonstrated statistically significant gains in both



intelligibility measures, single-word speech intelligibility (10% improvement) and EoU for sentences (11% improvement). These significant gains in speech intelligibility can be attributed to the nature of the treatment, in which cues for increased articulatory excursion and loudness of speech directly affect intelligibility. In other words, using the simple *mSIT* cues ('big mouth, strong voice') positively affected change in the perception of word and sentence clarity among naïve and experienced listeners.

The current findings are in line with those of previous studies: Levy et al. (2021) examined the effect of SIT intervention on narrative intelligibility among English-speaking children and adolescents (mean age = 10 years), with significant gains reported on outcome measures. Similarly, Moya-Galé et al. (2021b) applied the SIT intervention to French-speaking children (mean age = 8 years) and reported improved narrative intelligibility as well. Findings from the present study extends the application of SIT intervention to a group of adolescents and to the additional language of Hebrew. Although the treatment schedule differed from that of the previously reported studies, these results reinforce the potential of this treatment approach among individuals with dysarthria.

A notable difference between the present and previous studies was the choice of single-word stimuli for intelligibility judgments. The transcription-based, single-word intelligibility measure is supported by the non-contextual nature of single words (Hustad, 2007), which allows for objective comparison of productions with a known target. Furthermore, using this measure was especially relevant for participants in the current sample, in which at least some were observed to have extremely limited expressive language, characterized by single words or short phrases.

Sentence-level intelligibility measures (Levy et al., 2021; Moya-Galé et al., 2021b) reflect naturalistic conversational speech and were relevant to at least some of the current participant sample. Judgment of sentence-level intelligibility is typically conducted via naïve listeners, similar to the transcription procedure of the single-word intelligibility measure noted above. However, in the current study, an a priori decision was made to include experienced listeners (SLPs blinded to treatment group and time of assessment). This decision was guided by the observed speech and language deficits of the participants as well as the less rigorous treatment schedule in order to detect even slight changes following treatment.

Results of post-treatment intelligibility measures within the Beataalk group revealed modest gains in intelligibility, albeit non-significant. As this approach relies on repetitive and intense practice of syllable-level productions, it is possible that these skills were not generalized to word- and sentence-level productions. Instead, gains may be expected in phoneme-level productions, as detailed next.

Yet, despite the fact that group-level change was not significant for either intelligibility measure (word or sentence) for the Beataalk participants, a closer inspection of the data revealed improved sentence EoU scores for five out of the eight participants in this group. These participants demonstrated increases of 9–21% in sentence EoU scores (16% on average). Upon further inspection, these participants demonstrated moderate pre-treatment intelligibility scores, both word and sentence level. In addition, anecdotal reports from the treatment team indicated that these participants exhibited high engagement and motivation levels during the treatment. This finding indicates that the Beataalk treatment may positively affect sentence-level intelligibility, as judged by experienced listeners, at least for participants with moderate speech and intelligibility deficits as well as motivation for improvement.

Articulatory accuracy

Impairment to the articulatory subsystem is a main contributor to intelligibility deficits in individuals with developmental dysarthria, in comparison with other subsystems (Lee et al., 2014). Therefore, articulatory accuracy was also chosen as a key outcome measure of the current study. Gains in articulation or lack thereof, differed between the two treatment groups.

Participants in the *mSIT* demonstrated no change in PCC scores from pre- to post-treatment. The lack of improvement of the *mSIT* group is seemingly incongruent with results of improved single-word and sentence-level intelligibility following treatment; however, several factors may explain this discrepancy. First, as described in the outset, *mSIT* is a global approach, designed to address overall clarity of speech and is not necessarily expected to elicit change on the phoneme level. Although improved consonant production may potentially be a by-product of increased effort and intensity of speech, it was not practiced directly in the treatment sessions. A key principle in the study of neural plasticity is *specificity*, which states that only practice of the specified task will elicit change on the neural level of this task (Bunton, 2008; Ludlow et al., 2008). Meaning, improvement is expected only in the functions actually being practiced. Second, despite the inherent relation between speech sound production and overall intelligibility, assessments in each area are not necessarily fully reflective of the other (Kent et al., 1994; Miller, 2013). Finally, factors other than articulation, such as phonatory and prosodic factors (Chen et al., 2018), may also contribute towards improved intelligibility scores following treatment, but will not affect articulatory accuracy scores.

Participants in the Beataalk group demonstrated statistically significant gains (11% increase) in articulatory



accuracy. This improvement supports results from a previous study (Icht, 2021), in which articulatory accuracy on the PCC measure increased significantly for participants with dysarthria and reduced speech intelligibility following group treatment. These findings can be directly attributed to the intensive practice of speech sound production during the treatment sessions, which included multiple and intense repetitions of the targeted sounds during practice, as well as production within increasingly complex strings of sounds. For example, in order to produce the *kickdrum* sound (/p/), participants must engage a strong lip seal as well as increased intra-oral pressure, relative to a simple production of the phoneme /p/. These factors are consistent with the PML, in which intensity of practice, a random practice schedule (as related to the practice of individual sounds), and complex targets enhance the acquisition and retention of the target speech skill (Edeal & Gildersleeve-Neumann, 2011; Maas et al., 2008). The improvement in the PCC measure among participants in the Beataalk group, reflecting increased production accuracy of the target speech sounds, may be of clinical significance, especially for those participants who are minimally verbal and rely primarily on single-word or short phrases in daily output. Therefore, the improvement in the target speech sounds can have significant impact on these short and frequently used utterances. Furthermore, this accuracy may also be reflected in the visual cues of the target consonant (e.g., improved lip closure), which may, in turn, improve the speaker's comprehensibility (intelligibility with contextual cues) of the target spoken message.

Voice measures

Individuals with developmental dysarthria typically demonstrate impairment to vocal quality, which may affect both the intelligibility and naturalness of speech production (Miller, 2013; Schölderle et al., 2016). Results of the voice measures in the current study (jitter, shimmer, MPT) revealed comparable gains across treatment groups. Participants in both the *mSIT* and Beataalk group demonstrated gains post-treatment in the measure of jitter and improved MPT (or a trend of improvement). These findings are indicative of improved functioning at the respiratory and laryngeal levels and may be attributed to the increased respiratory effort and breath control achieved during both treatments.

During the *mSIT* intervention, a primary speech cue is to speak with a 'strong voice,' which enhances respiratory effort and is reflected in the 41% increase of MPT among participants in this group. These findings are consistent with gains reported following LSVT LOUD treatment among children (Boliek & Fox, 2017) and an adult (Moya-

Galé et al., 2021a) with CP and dysarthria. For the Beataalk participants, a gain in MPT was also observed, yet smaller in size (18% increase, marginally significant). However, the mechanism of increased vocal effort during the Beataalk treatment is assumed to be different from that of *mSIT*. The technique of beatboxing is similar in various aspects to singing, in which an emphasis is placed on increased respiratory control and muscle strength (StegemLINK et al., 2017), in order to produce different rhythms and tempos. Practice of the various beatboxing patterns, from simple to complex, promotes integration and coordination of the breath with phonation, leading to improved respiratory control and subsequently MPT (Thorpe et al., 2001).

A review of the jitter and shimmer (perturbation measures) results revealed a significant decrease in jitter values for both groups (41% decrease for *mSIT*, 58% decrease for Beataalk), whereas no significant change was noted for the measure of shimmer. Jitter is a measure of stability of the vocal fundamental frequency and is impacted primarily by vocal fold vibratory control. Higher jitter values are associated with lower vocal quality and pathological voice (Teixeira et al., 2013). In the current study, pre-treatment jitter values for the *mSIT* group fell nearly within typical range (< 0.7%; Maryn et al., 2009), while atypical values were noted for the Beataalk group (1.89% on average). Both groups demonstrated average values that fell within or nearly within normal range following treatment, highlighting the positive impact of both approaches on vocal stability and quality. The discrepancy between pre-treatment jitter values between the *mSIT* and Beataalk groups may indicate a larger treatment effect for the Beataalk group in this measure. This can be attributed, in part, to the nature of the Beataalk intervention, in which beatboxing-like practice positively impacts voice and resonance characteristics (Buescher & Sims, 2011; De Torcy et al., 2014). Shimmer outcome measures revealed no significant change post-treatment for either of the groups. It should be noted that participants in both groups demonstrated, on average, high shimmer values prior to treatment (> 3%; Maryn et al., 2009), and decreases following treatment were relatively modest and non-significant. The lack of change for the measure of shimmer also has precedent in previous studies: Chen et al. (2018) reported group differences between children with CP and dysarthria and typically developing children on the measure of jitter, but not shimmer.

Vowel acoustics

The reported acoustic changes of the first formant (F1) for select vowels following treatment provide physiologic support for the perceptual gains discussed above.

Participants in the *mSIT* group demonstrated increased F1 values for the low vowel /a/, indicative of greater opening of the mouth (e.g., jaw lowering; Johnson et al., 1993), and consistent with both loud (Wenke et al., 2010) and clear speech (Ferguson & Kewley-Port, 2002; Song, 2017; Whalen et al., 2004). Participants in both the *mSIT* and *Beatalk* groups demonstrated increased F1 values for the high, back vowel /u/, which is similarly associated with clear speech and/or increased vocal effort (Ferguson & Kewley-Port, 2002; Wenke et al., 2010). Interestingly, greater F1 values for /u/ do not necessitate a lowering of the tongue, as evident for the vowel /a/; Song (2017) reports that, in fact, the tongue position for the vowel /u/ in clear speech remains high, and changes to acoustics (e.g., higher F1) may be associated with other adjustments in the vocal tract (e.g. lip rounding).

In contrast to F1, no changes were noted to F2 following treatment, for either of the treatment groups. These findings parallel results from Levy et al. (2020b), in which French-speaking children with CP demonstrated no changes to F2 during 'big mouth' and 'strong voice' cued speech. These results are not entirely surprising given that changes to F2 rely on anterior-to-posterior lingual movements (Lee et al., 2015), a noted difficulty among individuals with CP (Ansel & Kent, 1992; Nip et al., 2017).

Consistent with F2 findings, namely a lack of treatment effect, no differences were noted for vowel space measures, *tVSA* and *FCR*, for either group. These findings correspond to those of previous studies demonstrating reduced sensitivity of the *VSA* measure in group differentiation (e.g., dysarthria and controls) as well as in correlation with single-word speech intelligibility. Sapir et al. (2010) failed to find differences between participants with Parkinson's disease and control speakers with the *VSA*, and Allison et al. (2017) reported a correlation only between sentence-level speech intelligibility and *VSA* among children with CP, but not single-word intelligibility. The findings of the current study also highlight the lack of direct association between perceptual distinction and acoustic correlates (Lansford & Liss, 2014).

A possible explanation for the lack of change among vowel space measures may also be related to treatment intensity, such that a more intense treatment schedule may yield significant differences in these measures following treatment. Further studies are necessary to test this possibility, particularly in light of findings from Carl and Icht (2021), in which both measures, *tVSA* and *FCR*, successfully distinguished between Hebrew-speaking typically developing participants and participants with dysarthria.

LIMITATIONS AND FUTURE DIRECTIONS

Given the preliminary nature of this study, several treatment and study design-related factors may limit its generalization and support the need for further research. One possible limiting factor is the heterogeneity of the participant groups. As typically characteristic of individuals with CP and other motor speech disorders, a wide range of factors may impact the application of treatment and its results, including co-morbidities, functional status, emotional and motivational factors, as well as type and severity of dysarthria. Future research with this clinical population may choose to limit these potentially compounding factors.

An additional limitation of the current study is the treatment schedule, which was less intensive than other relevant intervention protocols for individuals with developmental dysarthria (e.g., Levy et al., 2021; Moya-Galé et al., 2021a; Pennington et al., 2013). It has been suggested in the treatment literature that a greater treatment intensity (e.g., treatment hours per day and/or week) may have yielded greater gains in outcome measures in both treatment groups. However, the implemented schedule of weekly sessions was inherently guided by practical considerations, in which both the participants and treatment personnel were available on a limited basis for treatment provision. This treatment intensity is also a better reflection of the schedule of services provided through the educational system. Importantly, in addressing the topic of optimal treatment intensity, Baker (2012) notes that across several speech and language disciplines, a higher treatment intensity does not necessarily result in greater gains. Baker adds that issues such as adequate goal selection, as well as factors relating to practice and feedback, are equally necessary to consider. Unquestionably, further research is necessary to determine the ideal treatment dosage for motor-based speech interventions.

The study design, in which outcome measures were assessed once preceding and once following the treatment, is also a noteworthy area of future research. In order to determine both the stability of participant baseline abilities and the long-term effects of a treatment, target measures should be assessed on multiple occasions preceding treatment, as well as immediately succeeding and with a delayed interval of time following treatment (follow-up). Due to COVID-19 social restrictions, follow-up was not possible in the current study. Further studies should directly assess long-term effects of these treatments.

Finally, the choice of stimuli for intelligibility and articulatory measures may be expanded and better controlled in future studies. Assessment materials in the current



study were limited due to the lack of standardized tools in Hebrew; however, non-standardized materials may be used for further research, including single-word stimuli with additional phonological contrasts, as well as sentence stimuli of varying lengths and morpho-syntactic complexity. Similarly, future research may choose to incorporate additional acoustic measures including speech rate (e.g., Carl et al., n.d.), and vowel acoustics, including F2 slope of diphthongs (e.g., Chen et al., 2018) and variability of formant values (Carl et al., 2020).

SUMMARY AND CLINICAL IMPLICATIONS

The results of this study are encouraging for the application of both the Beataalk and *mSIT* approaches for Hebrew-speaking adolescents and young adults with developmental dysarthria. Although preliminary in nature, the current results indicate positive gains in intelligibility or articulatory accuracy, as well as in voice measures.

As evident from the differentiated results, each treatment may be more effective for a distinct set of impairments. Subsequent to a thorough evaluation to determine the most affected subsystems and most prominent speech deficits, the following clinical guidelines may potentially be used: The *mSIT* approach may be most suitable for treatment of general intelligibility deficits, that may result from impairment to several speech subsystems. These may include reduced intelligibility, imprecise speech production, poor breath control, reduced loudness, reduced pitch control, and prosodic impairment. The Beataalk approach may be more appropriate for treatment of more specific intelligibility deficits, namely imprecise consonant production and segmental-level distortions, as well as poor vocal quality. However, it is important to re-evaluate individual speech abilities during the course of the intervention process, while applying the most relevant approach in light of evolving clinical needs.

The clinical benefits of both treatments may include several other factors. First, both treatment approaches are simple to implement. The *mSIT* intervention includes cues that can be easily delivered and understood and therefore have direct impact on modifying speech production. Similarly, the Beataalk approach relies mainly on imitation of target sequences and can be performed even by children and delivered by non-professional personnel. Both treatments can also be practiced outside of the immediate treatment setting. Second, both treatments support the effectiveness of treatment provision within a group setting, with obvious economic benefits in terms of practical considerations (e.g., personnel, scheduling), as well as benefits of motivation and engagement among partici-

pants (Backus, 1952). This factor of motivation and engagement is especially important for children and adults with developmental speech deficits and their families, as evidenced by parental reports (Pennington et al., 2020). Third, both treatment approaches are cross-linguistic and cross-cultural in nature, as the *mSIT* cues seem to be appropriate for speakers of different languages, and the target sounds of the Beataalk treatment are common to many phonological inventories (McLeod & Crowe, 2018). Finally, the current study also suggests positive effects of treatment of developmental dysarthria in adolescents and young adults, a group that is the focus of only limited interventions reported in the pertinent literature (e.g., Moya-Galé et al., 2021b).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon request. The data are not publicly available due to privacy or ethical restrictions.

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