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Clinical Focus

Dynamic Temporal and Tactile Cueing: A Treatment Strategy for Childhood Apraxia of Speech

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Purpose: The purpose of this article is to describe a treatment approach, Dynamic Temporal and Tactile Cueing (DTTC), and to provide clinicians and clinical researchers a clear understanding of the theory and principles that contributed to the design of the treatment as well as the clinical decisions that must be made when implementing it. While brief descriptions of DTTC have been provided in textbooks, a complete summary of the rationale, essential elements, method, and procedures has not yet been published. Such a summary is important so that clinicians can gain a better understanding of and more confidence in using the method for appropriate children. Furthermore, this article provides clinicians and clinical researchers essential information for measurement of fidelity.
Method: The important elements of the DTTC method with rationale for their inclusion are described. The temporal hierarchy of DTTC is depicted, and the dynamic procedure is described in detail, with suggestions for fidelity measurement. Finally, a discussion of important decisions clinicians must make when implementing DTTC is presented.
Conclusions: The goal of DTTC is to improve the efficiency of neural processing for the development and refinement of sensorimotor planning and programming. The rationale for DTTC in general, as well as the key elements important to its administration, are supported by models of speech production and theories of motor learning. Important clinical decisions regarding stimuli, organization of practice, and feedback are based on principles of motor learning in order to facilitate acquisition, retention, and continued improvement of motor speech skills.

Children with severe speech sound disorders (SSDs) present particular challenges to the clinician. Some children who are nonverbal or minimally verbal may have been in therapy for a considerable time with little or no progress, even in the context of relatively good language comprehension and attention. This may be particularly true for children with childhood apraxia of speech (CAS) whose difficulty in sensorimotor planning and programming speech movement has not responded to traditional methods of treatment for phonology and articulation (Strand, Stoeckel, & Baas, 2006). There are a number of treatment approaches that have been described for CAS (Murray, McCabe, & Ballard, 2014), but most approaches do not specifically target the child with very severe difficulty with praxis for speech.

The purpose of this article is twofold: (a) describe a treatment approach, Dynamic Temporal and Tactile Cueing (DTTC), which was designed specifically for severe SSD, especially CAS, and (b) provide clinicians and clinical researchers a clear understanding of the theory and principles that contributed to the design of the treatment and to clinical decisions that must be made when implementing DTTC. While several studies examining treatment efficacy for DTTC have been reported (Baas, Strand, Elmer, & Barbaresi, 2008; Maas, Butalla, & Farinella, 2012; Maas & Farinella, 2012; Strand & Debertine, 2000; Strand et al., 2006), a complete summary of the rationale, essential elements, method and procedures, and important issues in clinical thinking in the application of DTTC has not yet been published. Such a summary is important so that clinicians can gain a better understanding of and more confidence in using the method for appropriate children and so that clinicians and researchers have more information for measurement of fidelity.

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Rationale for DTTC in Treating CAS

The goal of any speech treatment focused on the level of impairment is to address and facilitate those neural processes that are inefficient or not adequately developed. The goal of DTTC is to improve the efficiency of neural processing for the development and refinement of sensorimotor planning and programming, especially specification of movement parameters for acquisition of speech motor skill, as well as to provide strategies to enhance retention.

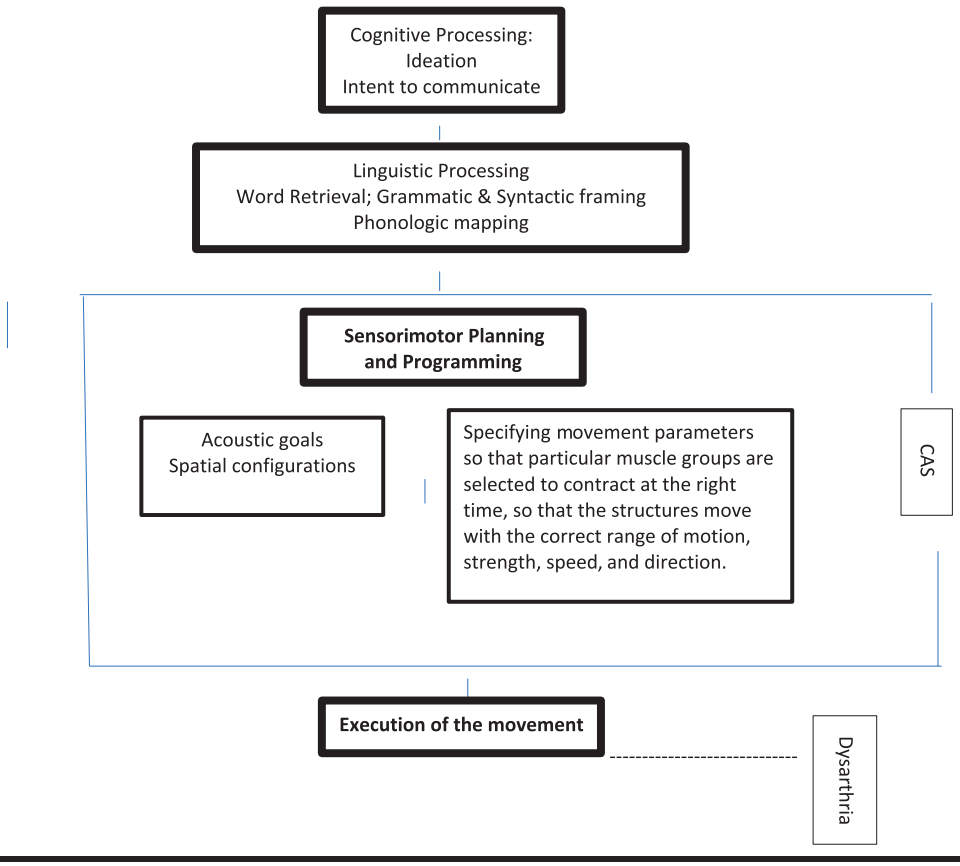
The following section provides a rationale for DTTC by describing where it fits in a model of speech production, the theoretical framework, and why this motor-based treatment is important in treating CAS. This is followed by a description of those children for whom DTTC was designed and for whom it is appropriate.

Theoretical Framework for DTTC in the Treatment of CAS

Figure 1 is a very simplified conceptualization of fundamental processes underlying speech production (based on Caruso & Strand, 1999; Kent, 2000; Kent, Adams & Turner, 1996; Rvachew & Brosseau-Lapre, 2012; Van der Merwe, 2009, Van der Merwe & Steyn, 2018). The model depicts how linguistic input is translated via sensorimotor planning and programming to execution of movements resulting in acoustic output. The term *praxis* is defined as the conception and planning of a motor act (Stedman, 2005) and is often used to denote sensorimotor planning and programming of intended movement for speech. Sensorimotor planning for speech involves establishing the spatial and acoustic goals, while sensorimotor programming for speech refers to the actual specification of movement parameters (i.e., instructions for the timing of muscle contraction so that specific structures move in the right direction, at the right time, with the right speed and force to reach a specific articulatory configuration). The execution level refers to the actual movement of the muscles themselves. While CAS is thought to be due to deficits in sensorimotor planning/programming, dysarthria is often due to weakness from spasticity or flaccidity of the musculature itself or to deficits in basal ganglia and/or cerebellar circuits, resulting in reduced motor control (e.g., cerebellar ataxia, dyskinetic cerebral palsy).

DTTC focuses treatment in the sensorimotor planning/programming levels by focusing on facilitating more accurate movement for specifically chosen stimuli. Through repeated practice trials, DTTC aids the development and refinement of motor programming by providing auditory

Figure 1. Simplified conceptualization of fundamental processes underlying speech production. CAS = childhood apraxia of speech.



and visual models, shaping the movement through slowed rate and visual and tactile cues, adding and fading cues as needed, providing specific feedback about the movement (knowledge of performance [KP]) early on, and fading to knowledge of results (KR) to facilitate learning and retention.

Because DTTC is designed to improve motor skill, it should adhere to theories regarding motor learning. One theory, from which much of the research in motor learning arose, is schema theory (Schmidt, 1975, 2003), which was intended to explain discrete actions (fast simple movements vs. complex movements; Schmidt, 2003; Wulf & Shea, 2002). Therefore, many of the principles of motor learning (PML) that came from subsequent research focused on these discrete actions. While more research is needed, it has been suggested that many of these principles may be applicable to speech production (Edeal & Gilderlseeve-Neumann, 2011; Maas & Farinella, 2012; Maas et al., 2012, 2008).

Schmidt (1975, 2003) proposed the generalized motor program (GMP), which Wulf, McNevin, Shea, and Wright (1999) describe as representing a centrally stored class of movements that are invariant (e.g., a sequence of movement elements, as well as relative force and relative timing). The GMP may be thought of as a general sketch or framework that is specified before movement begins and can be adapted to particular situations. Schmidt (2003) theorized that, through practice, the learner had to acquire the GMP that defined the overall structure of the action and learn the "schemata" that allowed the movement to meet any current task demands. He described a schema as a relationship between outcomes from previous attempts at executing motor programs and the specifications of movements used during those attempts. Two separate schemas are described by Schmidt (1975): Recall schema is the relationship between parameters (e.g., overall movement duration and overall force) for the motor program on each trial and the outcome achieved. A recognition schema is the relationship between past sensory consequences generated by executing the motor program and the outcomes and allows the learner to predict the sensory consequences that should occur upon execution of the motor program. Motor learning according to this theory, then, is the development of the GMP, as well as the recall and recognition schemas, due to practice and experience (Schmidt, 2003).

It is plausible many children with severe CAS have not efficiently developed the motor programs and schemata necessary for accurate speech production and/or have inefficient proprioceptive feedback mechanisms (Terband, Maassen, Guenther, & Brumberg, 2009). Because schema theory emphasizes how one may learn new programs and/or adapt existing programs to new conditions or goals, it is a logical theoretical framework for the DTTC method. The goal of DTTC is to improve the efficiency of sensorimotor planning and programming processes to improve speech production, and the methods in DTTC may facilitate both the acquisition of the GMP as well as recall and recognition schemas.

Schmidt (1975) describes four things a learner stores when attempting volitional goal-directed movement: (a) the initial conditions (e.g., position of the jaw, lips, and tongue; auditory and visual targets), (b) the response specifications for the motor program (e.g., range and direction of movement, speed, force), (c) the sensory consequences of the response produced (e.g., proprioception of articulator movement as well as the acoustic output), and (d) the outcome of that movement (KR). DTTC provides the child with knowledge of the target and places emphasis on initial conditions, drawing the child's attention to and increasing awareness of proprioceptive processing. Modeling and provision of KP in which the child is given specific information about their errored movement helps the child refine the appropriate response specification (e.g., direction, range, speed, force) for the intended movement. The initially slowed rate and use of simultaneous production provide more time for the proprioceptive feedback, while continuously moving toward normal and natural rate refines the motor program. The clinician facilitates the child's knowledge of the outcome by providing KR (after fading KP). The continuous practice with fading of cues (see Temporal Hierarchy and Cueing Strategies section) allows the child to develop the GMP as well as adaptations to different task demands (e.g., different words, syllable shapes).

Identifying Children With CAS

When choosing a treatment approach that intends to address the underlying area of impairment, differential diagnosis is essential (Strand, 2017; Strand, McCauley, Weigand, Stoeckel, & Baas, 2013). Clinical researchers have long described a subset of children who exhibit SSDs due to difficulty with praxis for speech (Caruso & Strand, 1999; Crary, 1993; Morley,1965; Rosenbek & Wertz, 1972; Yoss & Darley, 1974). However, agreement on how to diagnose this level of impairment has been somewhat controversial.

There is now increasing consensus regarding the behavioral characteristics associated with CAS (e.g., Murray et al., 2014; Shriberg, Lohmeier, Strand, & Jakielski, 2012; Shriberg, Potter, & Strand, 2011; Strand, 2009; Strand et al., 2013). Table 1 lists those characteristics that are often present but are not likely to be discriminative (because they are seen in all types of SSD) as well as those that are more likely to be discriminative in that they occur more frequently and pervasively in children with CAS than in other SSD subgroups. Support for this list comes from the literature cited earlier in this paragraph, more recent work focused specifically on identifying markers for CAS (Shriberg et al., 2017b, 2017c, 2017d), and personal observations of children with CAS during both assessment and treatment over many years.

There is also increasing consensus that CAS is due to inefficiency in sensorimotor planning/programming processes for speech (Murray et al., 2014; Shriberg et al., 2017a; Strand et al., 2013; Van der Merwe & Steyn, 2018). The types of CAS characteristics noted above reflect that level of

Table 1. Commonly accepted characteristics of childhood apraxia of speech (CAS).

Characteristics often present but not discriminative as they may occur with any SSD
Limited consonant and vowel repertoire
Use of simple syllable shapes
Frequent omission of sounds
Numerous errors: poor standard scores on articulation test
Poor intelligibility
Characteristics more likely to be discriminative for CAS
Awkward movement from one articulatory configuration to another[a]
Groping and/or trial-and-error behavior[b]
Presence of vowel distortions
Prosodic errors (i.e., lexical stress errors, equal stress, segmentation)
Inconsistent voicing errors[c]
Consonant distortions due to blending of manner (e.g., in between an /m/ and /b/)
Intrusive schwa[d]
Inconsistency of word or phrase production over repeated trials[e]

Note. SSD = speech sound disorder.

[a]Movements may be visibly awkward or clumsy as the child attempts the continuous movement within and across/between syllables. [b]Prevocalic groping or silent posturing, and occasionally searching articulatory behavior that takes place during sound production; this goes beyond the awkward movement within and across the syllable in that the movements are larger, last longer, and often occur in trial-and-error behavior. These are typically seen in elicited utterances rather than in spontaneous speech production. [c]Voicing errors often present are those where it is hard for the clinician to distinguish whether the sound was voiced or unvoiced, perhaps due to mistiming of onset of vocal fold vibration. [d]An intrusive schwa is common and occurs in both word-final (/bɛdə/) and within-word (/bɑɪək/) positions. [e]Inconsistency of target word production over repeated trials must be interpreted in the context of severity. Nonverbal or minimally verbal children with severe CAS may be quite consistent over repeated productions, especially early in therapy because they initially have difficulty changing any movement parameter, even with cues. At the same time, children with phonologic impairment who have been in therapy and are in the process of beginning to generalize may be quite inconsistent in production of the target sound(s) over repeated trials, perhaps because of self-correction.

impairment. Because CAS reflects a deficit in praxis for speech, DTTC is focused on treating that aspect of the disorder.

DTTC Method and Procedure

There are three core elements of DTTC that may differentiate it from other methods of treating SSDs: (a) the focus on the movement (rather than the sound or phoneme) in terms of modeling, cueing, feedback, and target selection; (b) emphasis on facilitating the child's intent to improve motor skills; and (c) attention to proprioception (see Focus on Movements Versus Phonemes, Intent to Improve Motor Skill, and Addressing Proprioception sections for broader description and rationale for these elements). DTTC was designed for children with more severe CAS and is not intended for long-term use. In my clinical experience, with appropriate dosage (at least three to four times per week), children will progress to the point where the methods used in DTTC are not needed (often less than a year), and the clinician will move to other methods for treating SSDs, including more linguistically based treatment.

The following subsections describe changes in terminology for the method and show a brief description of elements important at each level of the hierarchy. This is followed by a more complete description of the methods and procedure, including examples of types of cueing.

Terminology

Because DTTC is a type of integral stimulation (IS), which has long been used to treat both children (Milisen, 1954) and adults (Rosenbek, Lemme, Ahern, Harris, & Wertz, 1973), the method was originally described as "integral stimulation therapy" (Strand & Debertine, 2000; Strand & Skinder, 1999). IS, which emphasizes attention to the visual and auditory aspects of a particular speech target, was introduced in the 1950s in contrast to the traditional stimulus method used at that time, which was primarily an auditory approach (Mysak, 1959). IS simply refers to the method of having the child imitate a target produced by the clinician, asking the child to *listen to me/watch me/do what I do*, and the clinician's provision of feedback. As DTTC has been refined and studied for efficacy, Dynamic Temporal and Tactile Cueing (DTTC) has replaced the name "integral stimulation" (Strand et al., 2006) to illustrate more clearly the nature of the method.

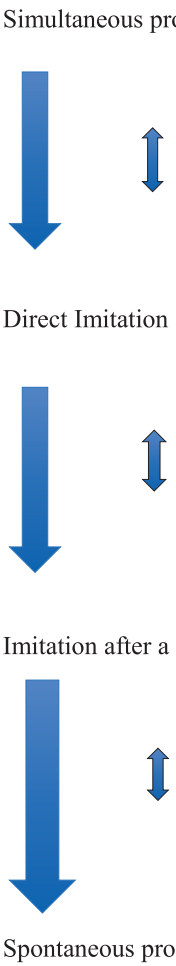
Fundamental to DTTC is varying the amount of time between the clinician's model and the child's imitative response as an important means of scaffolding the child's responsibility for movement specification. This is called the *temporal hierarchy*. Through the clinician's gradually lengthening of the time between model and response, the child gains autonomy in producing the movements for the utterance. The basic temporal hierarchy from simplest to more complex is as follows: (a) simultaneous production, (b) direct imitation, (c) imitation after a delay, and (d) spontaneous production in response to a question. The term *dynamic* was added to emphasize that visual, auditory, and, if necessary, tactile cues are added and faded as needed (specific descriptions of this are provided in the Temporal Hierarchy and Cueing Strategies section).

Temporal Hierarchy and Cueing Strategies

Primary strategies in DTTC include slowing rate at first, gradually moving toward a normal rate, varying prosody, and using gestural and tactile cues. Figure 2 illustrates the basic hierarchy and indicates the major steps to do at each level.

A complete description of the procedure follows, with headings for each level of the hierarchy. The levels of the hierarchy are not discrete, and clinicians may sometimes fluidly move back and forth when moving from one level to the next. Figure 3 illustrates the complete hierarchy, showing the dynamic nature of adding and fading cues, how

Figure 2. Basic Dynamic Temporal and Tactile Cueing hierarchy. Down arrows illustrate the hierarchical progression of each step, while the bidirectional arrows depict the dynamic nature of cueing back and forth between levels if transitions from one level to another are difficult. Procedures for each level of the hierarchy, when to begin to vary prosody for each level and when to move from one level to the next, are shown on the right.



The following occur in each level of the hierarchy:

During repeated practice trials at each level of the hierarchy

- Start slowly, making sure the child is watching
- Slowly move toward normal rate with practice trials
- Provide cues as needed, to shape accurate movement
  - Visual
  - Gestural
  - Tactile
- Provide more specific, knowledge of performance (KP), feedback at first
- Gradually move to knowledge of results (KR) as they become more accurate
- Fade all cues as quickly as possible
- Complete as many practice trials per sessions as possible

Add variation in prosody at each level of the hierarchy

- When to vary the prosody
  - When the child is accurate
  - When the child has maintained accuracy at normal rate for at least 10–15 trials
- How to vary the prosody
  - Produce the target quieter or louder
  - Produce the target with different emotion (e.g., sad, mad, happy, excited)

When to move to the next level of the hierarchy (e.g., from simultaneous to direct imitation)

- When the child demonstrates accurate movement at a normal rate over at least 10–15 trials; and
- When the child has varied prosody (with normal rate and accuracy) for at least 10–15 trials; and
- When the child shows no effort

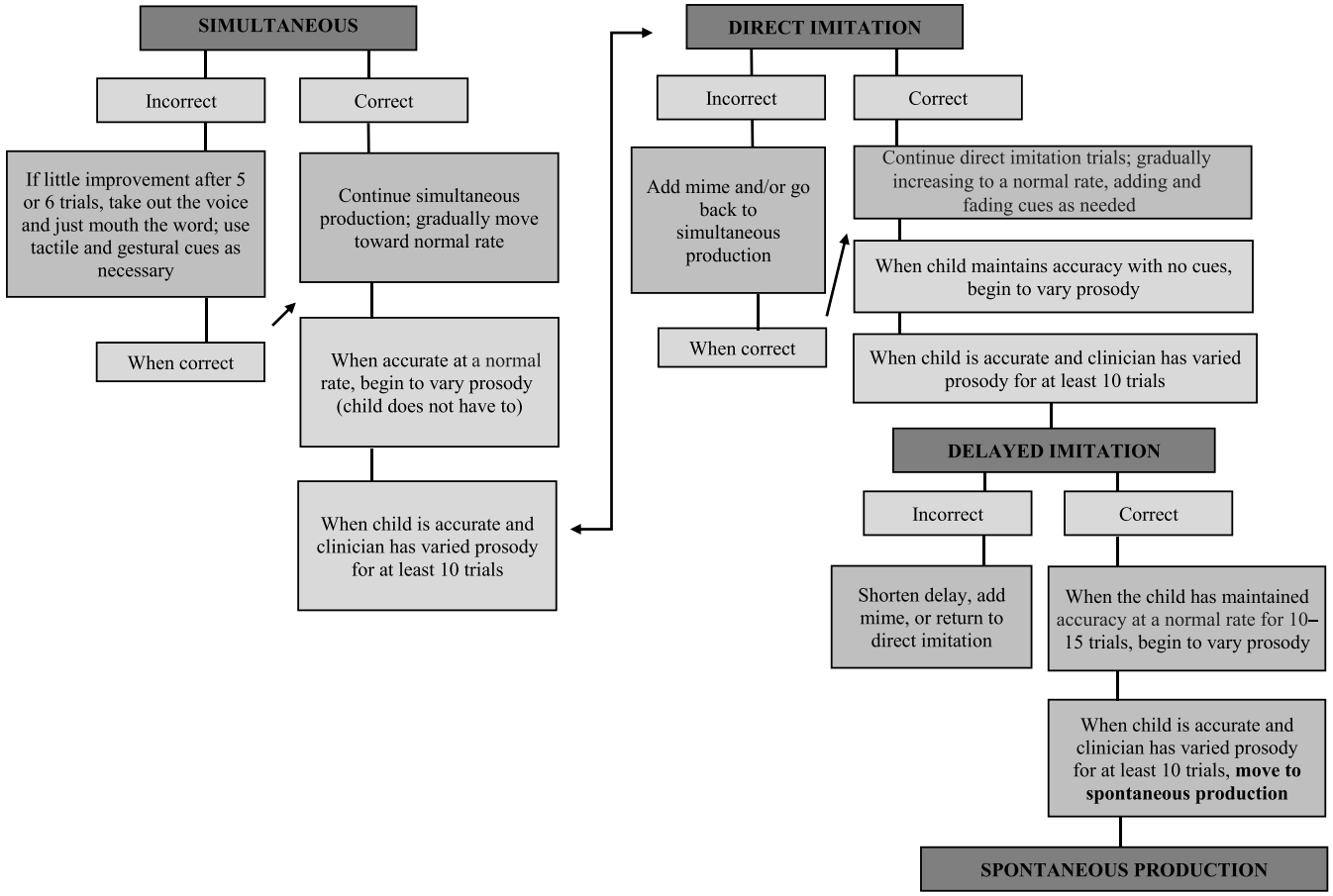
and when to vary prosody, and when and how to move from one level of the hierarchy to another.

Simultaneous Production

To begin the procedure, the clinician says the first target word, and the child repeats. If incorrect (typically, the child is not successful on the first attempt, as the clinician has likely chosen stimuli the child has not yet mastered), the clinician may repeat the model more slowly, adding a gestural cue such as pointing to retracted lips. If still unsuccessful, the clinician goes immediately to the simultaneous production level. First, the clinician helps the child achieve the correct jaw and lip positions for the initial articulatory configuration with attention given to the predictive articulatory posturing for the upcoming vowel. The child should stay in that position for a few moments to maximize proprioceptive processing and then simultaneously produce the utterance slowly (without segmentation), with the clinician, who will utilize tactile and gestural cues as needed (see Table 2 for additional examples of cueing strategies throughout all levels of the temporal hierarchy).

Sometimes, the child is not able to produce the movement, even in simultaneous production. If they are having difficulty achieving the initial articulatory configuration, adding phonetic placement strategies is helpful (e.g., placing a straw in the child's mouth to achieve lip rounding, then removing it, and asking the child to "stay there" in the rounded posture). Another strategy is to reduce the movement specification requirements by taking out the respiratory and laryngeal systems. Have the child silently and simultaneously imitate just the articulatory movement for the target word. This is often successful, although it may

Figure 3. Complete dynamic Dynamic Temporal and Tactile Cueing hierarchy illustrating when and how to move up or down the hierarchy.



take a number of trials. When the child can simultaneously produce the accurate movements for the word, gradually introduce a whisper and then the voice. As always, adding gestural or tactile cues to provide more support when needed is followed by fading that support as the child is showing more accurate movement. It is impossible to specify the exact type of cue or number of trials before fading cues, as that will vary from target to target (based on difficulty of the target for that child) and from child to child (based on severity of the apraxia and concomitant deficits). However, cues should be faded as soon as possible. Sometimes, only one or two cued trials are needed, and typically within 5–10 trials. It is common to attempt to fade cues and have to add them back in when the child falters, fading again after a few more trials.

Once the child can produce the word slowly and simultaneously with the clinician, continue with repeated practice trials, gradually moving toward a normal speech rate. Fade cues as soon as possible as movement accuracy improves (e.g., when the child has achieved appropriate lip rounding during the target word production over several trials, fade tactile or gestural cues). When the word or phrase is produced accurately with ease (no groping, self-correction, effort) and at a normal rate (over at least 10 trials, although that can be shorter if accuracy was achieved quickly), the clinician begins to vary prosody as she and the child continue to produce the word simultaneously. This step of varying prosody is done at each level of the temporal hierarchy (simultaneous, direct imitation, delayed imitation, and spontaneous production). There are two rationales for this. First, it provides variability of practice important to motor learning (Magill & Hall, 1990; Schmidt & Lee, 2005). Variability is introduced by saying something softer or louder, or with a different emphasis (happy or excited vs. sad or bored), which necessitates different movement specifications, especially for the respiratory and laryngeal muscles, despite the fact that the articulatory targets have not changed. Second, because many children with CAS have prosodic difficulty, it is important to emphasize prosodic contours along with articulatory accuracy from the very beginning. Changing up prosodic aspects of the target gives the child early practice in varying length, pitch, and volume of productions. Of course, during simultaneous production, the child cannot predict how the clinician will vary prosody and the clinician does not give any directions. The goal at this point of the temporal hierarchy is not to

Table 2. Examples of tactile and gestural cues for each level of the hierarchy.

When to use cues	Steps within each level of the hierarchy	Suggested but unspecified cues
	Simultaneous production: first few attempts at a target word or phrase	
First cued trial after initial direct imitation attempt	- Draw child's attention to the clinician's face - Repeat the model more slowly - May add a gestural cue (e.g., pointing to retracted lips, using fingers to thumb-closing gesture)	
Second cue and following	Have the child simultaneously produce the utterance slowly with the clinician	If the child cannot get to the initial articulatory position, may use phonetic placement techniques May add tactile cues if necessary, such as: - Use fingers to round the child's lips - Hold fingers under the jaw to reduce jaw opening - Use fingers to retract the child's lips - Other tactile cues the clinician feels may be helpful
If little improvement is noted after five or six trials at simultaneous	Reduce the movement specification requirements by taking out the respiratory and laryngeal systems; have the child just mouth the movements for the word silently with the clinician.	May also need to add gestural or tactile cues here as well. Again, fade cues as the movements become more accurate.
	Simultaneous production: continued practice	
Continued trials at simultaneous level When the child is accurate at a normal rate over 5–10 trials without cues	Repeat simultaneous production, slowly working toward accurate movement and normal rate Begin to vary prosody during your models (don't worry if the child does not vary prosody at this level).	- Slow rate if needed; gradually move to a normal rate. - Add and fade tactile or gestural cues as necessary with each response.
	Direct imitation	
When the child is accurate at a normal rate without cues over at least 10–15 trials	Move to direct imitation	- If they falter, may either go back to simultaneous or add a mime - Add or fade gestural or tactile cues as necessary with each response and fade as soon as possible - Slow a bit when needed, and continue to move to a normal rate
When the child maintains accuracy at a normal rate over at least 10–15 trials without cues	Begin to vary prosody, asking the child to "say it just like me"	Continue to add and fade gestural and tactile cues with continued practice trials (as described above) as necessary
	Delayed imitation	
When the child is accurate at a normal rate without cues over 10–15 trials and has varied prosody at least 10–15 trials	Move to delayed condition	If they falter, may either go back to direct imitation or add a mime Continue with delay trials, adding or fading cues as necessary
When the child is accurate at a normal rate over 10 or so trials in the delayed condition	Begin to vary prosody, again asking the child to "say it just like me"	
	Spontaneous production	
When the child is accurate, at a normal rate, and has varied prosody in delayed imitation	Move to spontaneous production elicited by a question or picture	At this point, no tactile or gestural cues should be needed. If they falter, go back to additional practice in the delayed condition.

Note. In providing feedback, use knowledge of performance (specific feedback such as "not so big"; "close your mouth a bit"; "can you make that tighter?"; "put your tongue back") at first, until the child is close to accurate, and then fade to knowledge of results (e.g., "good," "not quite"). Feedback should be frequent at first and gradually reduced as the child demonstrates refinement of the movement.

accurately imitate the prosodic production but rather to begin to vary prosody in any way. It is common for children to begin to vary prosody on their own, even though it is not required. Point out how they are "moving their voice," and reinforce this with positive reinforcement. When the child produces the word or phrase accurately at a normal rate and the clinician has at least modeled changes in prosody over about 10–20 trials, then the clinician moves to

direct imitation (asks the child to repeat the utterance after the clinician's model).

Direct Imitation

Even though children may have been successful for many trials in the simultaneous condition, they will often falter at the direct imitation level. If so, the clinician will go back to simultaneous production for a few trials and then try again. If the child falters again, the clinician may mime the movement (mouth the articulatory movements without voice) for the utterance as the child attempts saying the target in direct imitation. Typically, the clinician has to mime only a few trials before fading the mime and continuing with the voiced direct imitation (i.e., the clinician says the utterance, and the child attempts to repeat it). Fading the mime usually involves going from miming the whole word, to just miming the movement for the initial configuration, to finally fading the mime completely. If the child's response seems effortful or in error, however, the clinician returns to the entire mime or even back to simultaneous production. As with all cueing, the clinician should add and fade the mime as needed.

When the direct imitation is successful, the clinician stays at that step, providing additional practice trials that gradually move toward a normal rate. When the child easily produces the utterance with consistent accuracy and natural rate, the clinician begins to vary prosody. At this level (direct imitation) of the temporal hierarchy, the clinician asks the child to "say it just like me." Prosody can be varied, even with monosyllabic utterances by varying emotion and loudness (e.g., saying it as if excited, mad, or sad; saying it loudly or softly), while also making sure the child maintains accuracy and normal rate. If the production becomes less accurate, the clinician should go back to direct imitation without varying prosody and then work toward varying prosody again. (Some children who have severe difficulty with any prosodic variation may need part of each session devoted just to prosodic practice, especially with bisyllabic or multisyllabic words.) When the child produces accurate articulatory movements, maintains accuracy at a normal rate, and has varied prosody in direct imitation for at least 10–20 trials, the clinician moves to the next level of the hierarchy—adding a delay.

Delayed Imitation

Explain to the child that they should repeat the utterance, but this time "wait until I point to you" (or "touch your knee," etc.). If the child falters, the clinician may go back to direct imitation and/or add the mime, fading each cue as soon as possible. When the child has maintained accuracy at a normal rate for 10–15 trials at this delayed imitation level, begin to vary prosody. (If the child has slowed production in the delayed condition, work back to normal rate, maintaining accuracy before beginning to vary prosody.) After the child has successfully produced the utterance accurately at a normal rate and has varied prosody successfully for at least 10–15 trials in the delayed condition, move to spontaneous production.

Spontaneous Production

At this last level of the hierarchy, begin to elicit the utterance with a question (or picture). This is done randomly (one trial at a time, interspersed throughout the session while working on other targets). When the child is successful at spontaneous production on most trials across two to three sessions, then that target goes out of the training list and into a carryover phase (e.g., family members may elicit the spontaneous production of the target across various times, places, activities, etc.). See Measurement of Progress section for additional conditions for moving targets out of training.

Additional Factors Important Throughout DTTC Treatment

In order to avoid negative practice (potentially strengthening inaccurate movement), cues should immediately be added any time the child falters and then faded again as soon as the child improves in accuracy. This is a form of errorless learning, which is a therapy strategy that works to avoid or minimize errors. In DTTC, learners do not "practice" errors, in that they are provided with a gestural or tactile cue immediately following any error, hesitation, or faltering. These cues are faded and eventually removed, however, promoting self-awareness and self-correction. Errorless learning was incorporated into DTTC because the children with severe CAS could seldom improve production without cueing and would tend to reproduce inaccurate movement patterns over and over. While this form of errorless learning does in fact allow at least an initial error (and usually a series of errors as they move closer to the accurate movement), the cueing is provided in order to avoid repetitions of the same error pattern and to facilitate progressive acquisition of movement accuracy. There is support for errorless learning in the literature, particularly for cognitive impairment and aphasia (e.g., Fillingham, Sage, & Lambon Ralph, 2006; McKissock & Ward, 2007), but also for SSD treatment (Rudolph & Wendt, 2014).

In summary, the use of fading of cues as soon as possible at each level of the hierarchy helps the child to develop more independent skills. Early in therapy, children with severe CAS may require a number of sessions to achieve accuracy for any one stimulus item. Over time, however, and sometimes even with the first couple of months of treatment (especially if therapy is frequent), targets will be achieved more quickly.

Measurement of Progress

Monitoring children's progress in therapy is essential to both accountability and the clinical decision-making process (Olswang & Bain, 2004). There are many factors related to measuring progress depending on one's purpose (e.g., using quantitative vs. qualitative data, taking treatment data vs. probe data). While it is beyond the scope of this article to discuss all these issues, this section describes suggested strategies for monitoring progress during the acquisition phase and especially for making clinical decisions

regarding when to move items out of training and into a carryover phase.

Probe Testing

Many clinicians attempt to collect data during treatment as the basis for their decision making. Evidence from the motor learning literature suggests that treatment data may be quite misleading in that they give information only regarding changes as acquisition is occurring (performance during practice). Changes noted during practice do not predict performance outside the training sessions and do not measure retention or longer term maintenance (Maas et al., 2008). Consequently, DTTC uses probe testing, which involves randomly (nonsequential elicitations of the target in a random order) measuring production accuracy of current target words or phrases outside the treatment portion of the session. The primary purpose of the probes is to facilitate decisions regarding when to transfer target words or phrases from training to carryover strategies. In this context, the clinician is actually measuring progress toward acquisition. Continued probing of targets achieved, at longer intervals (e.g., every month or longer), should be used to measure retention.

Table 3. Example of probe data over one session and over 10 sessions.

a. Probe Session 1

Five stimuli	Five random productions each					Score
Hi	0	0	0	1	0	1
Bye	0	1	0	0	1	2
Mom	1	1	2	1	2	7
Mine	0	0	0	0	0	0
No	0	0	1	1	1	3

b. Example of 10 probe sessions

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	10
Hi	1	3	2	4	7	8	8	***9***	***9***	
Bye	2	2	2	7	7	6	***9***	***10***		
Mom	7	8	7	***9***	***10***					
Mine	0	0	0	0	0	2	2	4	2	4
No	3	2	2	4	3	5	6	9	8	7
New words are added when one of the above is taken out. Probes for new words begin the first probe session after training begins.										
Up (replaces mom)							1	2	3	6	9
Eat (replaces bye)										0	4
One (replaces hi)											**0**

Note. A score of 9 or 10 over two probe sessions meets criteria for going out of treatment and is shown in bold italics. New target items are shown below, with the onset of their probe data shown.

Clinician Decisions Regarding Probes

A number of decisions need to be made regarding how often to probe, in what context to elicit the target, methods of scoring, and setting criteria for a target to transfer out of training. When therapy is provided frequently (four to five times per week), probe testing every third session may be sufficient. If therapy is only once per week, probe testing may be done at each session. One may choose to collect probe data either before or after the therapy session, but this should be consistent across probes. The clinician must also decide the context in which they will elicit the target (i.e., direct imitation vs. answering a question). While a nonimitative response is a better measure of motor learning, direct imitation may minimize frustration for those with severe CAS, especially in the early stages of treatment. Eliciting five random productions of each target generally results in a reasonable sample and is practical for the busy clinician.

Scoring may be binary (right or wrong) or multidimensional. A simple multidimensional scoring system (e.g., 2 = *accurate*, 1 = *close*, and 0 = *inaccurate*) is one model and has been used to show more incremental change (Strand et al., 2006). For a score of 1, the clinician will need to provide an operational definition (e.g., one mild vowel or one consonant distortion). To obtain a "probe score" for each target, during each probe session, add the scores for the five random repetitions (e.g., 0, 0, 0, 1, and 2; yielding a score of 3, out of the possible total score of 10 [maximum score of 2 × 5 repetitions] of that target that probe day; see Table 3a). Table 3b shows the results over 10 probe sessions, indicating which targets had reached criteria along with new targets brought in.

The clinician will choose the criteria for when any target has been "mastered" and will go out of training and into a carryover phase. A criterion of a score of 9 or 10 over three probe sessions and observations of the child accurately producing the word or phrase randomly and spontaneously at least 90% of the time during at least two treatment sessions should allow good maintenance if carryover activities are incorporated at home and school. This may vary from child to child (e.g., if the child is in a situation where carryover strategies are likely not to happen, the clinician may want to use stricter criteria). When the child reaches the criteria for a target, that word or phrase is taken out of training and a new target item is added (see Table 3b). At first, it may take a number of sessions for a target to reach criteria, but as the child's motor skill improves, targets will reach criteria more quickly. When this happens, the clinician may bring in two new items when a target reaches criteria. Over time, the stimulus set size gradually increases, and the targets themselves increase in length and phonetic complexity.

Children exhibiting significant CAS typically need DTTC perhaps a year or so if therapy is provided frequently. By the time the set size increases to 10 or more items, the child has likely mastered all vowels across co-articulatory contexts, has improved movement accuracy and prosody, but still has some residual sound errors. More traditional methods of articulation or phonologic therapy may then be appropriate. Children with severe prosodic deficits may need continued work to improve lexical or phrasal stress, naturalness, and/or decrease segmentation.

Fidelity

Measuring fidelity is extremely important in treatment research (Kaderavek & Justice, 2010) to be sure the treatment studied was administered as designed. Fidelity measurement may also be another means of improving skill in the treatment method and reducing variability across clinicians. For both these reasons, possible difficulties in measuring fidelity must be considered when using DTTC. The primary aspect of DTTC that may pose problems for fidelity measurement is that the clinician is charged with making many online clinical decisions. Which cues to add and when to fade them will depend on the child's level of accuracy in each attempted response. Furthermore, the clinician will adjust the number of trials at each level of the hierarchy, depending on the rate of progress. For example, a child who has had significant difficulty with a particular movement or prosodic variation may need more practice trials at each level of the hierarchy and/or within each cueing strategy (e.g., tactile cues or mimes). The same child may need many fewer trials at each level of the hierarchy for a different target. Finally, all clinical decisions (including frequency of sessions, organization of practice within sessions, and/or the number of trials at any level of the hierarchy) are influenced by the child's fluctuating attention, comorbidities, and overall CAS severity. Although the hierarchy itself is prescribed and suggestions for types of cueing are given (see Table 2), the clinician ultimately decides what is best for that child, for that target, and for each practice trial.

Because clinicians make many online decisions during the administration of DTTC, it is probable that clinician skill and experience will affect efficacy of the method. DTTC treatment will likely be more efficacious and efficient when administered by more experienced clinicians or clinicians who have had specific training in and practice with DTTC. While this is the case for all treatment approaches, a dynamic approach such as DTTC is especially vulnerable. Research is needed to examine which variables (e.g., adding and fading cues, moving through the hierarchy) are most difficult to implement effectively.

Despite the fact DTTC involves many clinical decisions, it is important that high-quality implementation of the intervention be pursued. An example of a basic fidelity checklist for DTTC is provided in Table 4. The checklist was constructed based on a number of key ingredients for DTTC that include items related to intensity, focus on movement, use of the cueing hierarchy, contingent use of cueing methods, and recruitment of the child's attention to the clinician's face. The examples in Table 4 are specifically for severe CAS but would be amended for different levels of severity and would need specific operational definitions depending on the purpose of the fidelity measurement. For example, the two items "Used 4–8 targets," and "Used a modified block organization of practice" would be changed for children who are more moderate in severity. Other items (e.g., "Used appropriate # of practice trials") would be more clearly specified based on the clinician's or researcher's specific purpose and question. It is important that clinical researchers

Table 4. Example of fidelity checklist for severe childhood apraxia of speech (CAS) treatment session.

General observations per session (check those in which the condition was met)		
_____	Used 4–8 targets[a]	
_____	Used a modified block organization of practice[b]	
_____	Provided fading of feedback[c]	
_____	Sitting facing child; close to eye level	
_____	Reduced background noise; no distracting items near child	
_____	Gave the child reassurance and good instructions	
For each target (this would be repeated for each target practiced that session)		
Observed	Not necessary	
_____		Reminded them that "we are working on moving better so that speech is easier"
_____		Drew attention to the clinician's face when needed
_____		Periodically reminded them to "feel" the configuration or movement
_____	_____	If not successful at the first or second try, went to simultaneous production
_____	_____	Used phonetic placement if necessary
_____	_____	Took out the voice and made the articulatory movement only if necessary
_____		Used tactile cues when appropriate (at least 80% of the time)
_____		Started slowly and gradually worked toward a normal rate
_____		Added cues appropriately at least 80% of the time
_____		Faded cues appropriately at least 80% of the time
_____		Moved from simultaneous to direct imitation if conditions were met
_____		Moved from direct imitation to delayed condition if conditions were met
_____		Moved from delayed condition to spontaneous production randomly if appropriate
_____		Achieved appropriate number of practice trials over the session

[a]Used a smaller set size (four to eight targets) with functionality, syllable shape, and vowel content and length appropriate to the severity of CAS. [b]Practiced each target between 10 and 40 trials, with one or two targets receiving more trials than the other targets and perhaps more than one block of practice per session. [c]Feedback was faded (in both specificity and frequency) during practice within a block, as the child became more accurate (score if this was observed at least 50% of the time when appropriate).

clearly describe how DTTC was implemented and provide thorough participant description (including severity of the praxis deficit) when reporting treatment efficacy.

In summary, there is always the potential for high variability in effectiveness for any treatment across clinicians, depending upon education, years of practice, and individual variability in clinical skills. This is unavoidable. DTTC, however, provides additional potential for such variability because of its dynamic nature and the clinical decisions that need to be made. With free online video examples and video training, as well as the use of fidelity checklists, the variability across clinicians may be mitigated.

Clinical Decision Making in the Implementation of DTTC

There are a number of issues not directly related to the DTTC method and procedures that are discussed here in order to enhance the clinician's clinical thinking and decision making as they implement DTTC. These include the choice of treatment targets, organization of practice within a session, and types and timing of feedback.

Treatment Targets

No matter which motor approach one uses for treating CAS, a number of important decisions regarding treatment targets must be made (Jakielski, 2017; Maas, Gildersleeve-Neumann, Jackielski, & Stoeckel, 2014; Van der Merwe & Steyn, 2018). The clinician must decide how many stimuli to use at each session; the length, syllable shape, and phonetic content of the stimuli; and whether they should be real or nonsense words.

For children who have few words, parents (and, at times, the child) should also play a part in choosing stimuli so that the utterances are useful, meaningful, and motivating. Parents should be reassured that the words and/or phrases chosen for practice are just a vehicle to give the child the opportunity to practice the speech processing that is inefficient for them at this time. Because the clinician will not (and could not) teach the child every movement they will need for speech, stimuli are selected so they can provide practice in specifying movement parameters for a variety of syllable/word length and shapes.

First, the clinician must decide how many stimuli to target. PML can guide us in deciding on the size of an initial stimulus set, and in DTTC, this decision is based on severity. For children with severe CAS, initial acquisition of skill is very difficult, and more massed practice (i.e., fewer targets allowing for more practice productions) may significantly improve acquisition time (Magill, 1988; Schmidt & Bjork, 1992; Strand et al., 2006), which may in turn decrease frustration and increase the child's motivation. In DTTC, clinicians are encouraged to choose a minimum of five to six target utterances for the minimally verbal or nonverbal child to ensure enough practice yet avoid overhabituation of movement patterns and provide some variability of practice (more varied phonetic content and syllable shapes). This small set size, however, will increase over time, as the child's motor skill improves (refer to the Measurement of Progress section).

There is a large literature regarding target selection in treating SSDs, most of which refers to treating individual sounds for children with phonologic disorders (e.g., Gierut, 2001; Gierut & Hulse, 2010; Hodson & Paden, 1991; Powell, 1991; Storkel, 2018). While clinicians are very accustomed to choosing particular consonants as targets in treatment, clinicians implementing DTTC are encouraged to also think about vowels, syllable length and shape, and errors in prosody (e.g., segmentation, equal or incorrect stress) in target selection. The rationale for this is that DTTC does not focus on the production of a consonant or the linguistic elements of the phoneme but rather on the movement and prosodic accuracy of the syllable as a whole. It is important to select specific distorted vowels as targets in early treatment, always in the context of word (rather than in isolation), and across co-articulatory contexts. This is because vowel distortions are noted to be a common characteristic of CAS (e.g., Shriberg et al., 2012, 2011; Strand et al., 2013). Furthermore, vowel accuracy is important to intelligibility (Turner, Tjaden, & Weismer, 1995; Weismer, Jeng, Laures, Kent, & Kent, 2001).

A motor speech examination (Strand, 2017; Strand et al., 2013) and a spontaneous speech sample will allow the clinician to target those vowels that tend to be distorted and include them (or, if many, a couple of them) in the initial stimulus list. The child's current phonetic inventory, as well as those segments that are most easily visualized and tactilely cued, are also considered in determining the phonetic content of the initial stimulus set. The length and phonetic complexity of targets are based on the severity of the speech disorder and the communicative needs of the child. Prosody may also be targeted early by including reduplicated syllables (*mama, no no*), bisyllables (*uh oh, baby, mommy*), or easy short phrases (*me too, hi mom*) depending on the severity of the apraxia.

Because DTTC is designed for children with more severe CAS, clinicians are encouraged to use real words in stimulus selection, as they are more motivating to the child, are functionally important, and will facilitate carryover and retention. Nonsense words may be used if rationale supports it. For example, consider the target /'nænə/ (the child's name for his grandmother) chosen to improve production of the vowel /ae/ in a simple consonant–vowel–consonant–vowel. If the child has established and habituated a stereotypic utterance for that functionally important word (e.g., /'əma/ for /'nænə/), it might be very hard to extinguish the well-established /'əma/. In this case, one might bring out a doll or toy, give it the name /'bænə/ to establish a different response, and then change the name to /'mænə/ and, finally, /'nænə/. In addition, if a child has significant prosodic difficulty, as therapy progresses, one might allocate short segments of time during treatment and use nonsense words to practice easy iambic and trochaic patterns while improving flexibility and increasing speed (e.g., /bæ'bʊ:/ or /'tæmo/).

Organization and Variability of Practice

There is a difference between acquisition (motor performance) and learning (retention) of motor skill (Maas et al., 2008; Schmidt & Lee, 2005). Decisions that facilitate acquisition of the motor skill (improvement of the movement accuracy for the target, during the treatment sessions, with cueing) may negatively influence retention. While this literature led to suggestions for organization of practice in DTTC, it should be noted that the principles derived from simple tasks may not always extend to speech, especially in children (Maas & Farinella, 2012). Furthermore, Wulf and Shea (2002) provide evidence that the research regarding organization of practice may not always apply to children, and/or in learning complex movement, providing support for the suggestions for organization of practice in DTTC for children with severe CAS.

Massed Versus Distributed Practice

Massed versus distributed practice refers to how practice is distributed over time, either the time between trials or the time between sessions. Distributed practice has been shown to facilitate retention in nonspeech motor learning (e.g., Shea, Lai, Black, & Park, 2000); however, there is a paucity of evidence in the speech motor learning literature. Furthermore, there are likely interactions with factors such as practice schedules and amount of practice (see Maas et al., 2008) that make this decision difficult for clinicians. When using DTTC, it is suggested to begin with frequent, short sessions (e.g., four to five times per week for 0.5 hr vs. once per week for an hour). There is some evidence to support this (Edeal & Gildersleeve-Neumann, 2011; Strand et al., 2006), but more empirical testing is needed.

Practice Variability

Practice variability refers to whether the practice is constant (e.g., throwing a ball over a particular distance) versus variable (throwing a ball across varying distances). Investigations of nonspeech movement suggest variable practice facilitates retention (e.g., Wulf & Schmidt, 1997); however, interested readers should see Schmidt and Lee (2005) for a discussion of variables that relate to the impact of variable practice. Children who have severe CAS have great difficulty establishing accurate movements for speech targets at first, and variable practice only makes that more difficult. DTTC incorporates constant movement early in practice, with variability (e.g., changing rate, varying prosodic contours) of practice brought in after the child is accurate at each level of the hierarchy. This is consistent with Rosenbek et al. (1973) who used more constant practice with three adults with acquired apraxia of speech early in treatment, moving to more variable practice later to improve motor learning.

Blocked Versus Random Practice

The implications of blocked versus random practice are important for clinicians to consider when making decisions about how to schedule practice within a session. Blocked practice refers to practicing one target (in DTTC, this would be one target item such as a word or a short phrase) over and over without intervening stimuli. In random practice, the same word would never be practiced on consecutive trials. For discrete nonspeech movement, most experiments show that blocked practice results in facilitation of acquisition of the movement pattern, while random practice of the movement pattern showed better retention (Shea & Morgan, 1979; Wulf & Lee, 1993).

This poses a problem for clinicians who work with children with severe CAS, as those conditions that facilitate retention (e.g., random practice) make it extremely difficult for children to develop accuracy for a target word or phrase. Therefore, DTTC is designed to employ a "modified block" practice design that begins with blocked practice and moves to shorter blocks and finally random practice. This is consistent with Shea, Kohl, and Indermill (1990) who published data indicating that blocked practice benefited acquisition early in practice with the benefits of random practice occurring later. This decision was also influenced by Wulf and Shea (2002), who make two points that may apply to motor learning in speech intervention. First, they note, "when the tasks are more difficult because of high attention, memory, and/or motor demands (or when learners are relatively inexperienced), random practice may *overload* the system and thus disrupt the potential benefits of random practice" (p. 189). Second, they question the generalizability of results from simple motor tasks in laboratories to the learning of complex motor skills. Finally, Maas and Farinella (2012) examined the relative effects of random versus blocked practice in CAS treatment, finding mixed results, suggesting that the findings in nonspeech motor learning may not extend to speech in all cases.

Modified Block Practice in DTTC

All words in a carefully devised training list should be practiced each session. For children with more severe CAS, this will be done in blocks of practice, which will reduce in size and frequency, moving to random practice as accuracy improves. Early in DTTC treatment, stimuli may be practiced in blocks of anywhere from 20 to 50 practice trials (depending on the child and how close they are to accurate movement for the target) for each target in succession. For those children beginning therapy who have no or very little speech, modified block practice may take the form of choosing one or two targets for additional trials within each block and/or adding an additional block of practice in the session. The other three to four stimulus targets would receive one block each during the session (see example on Table 5). This often results in quicker acquisition of those one or two chosen targets, increasing the child's motivation and building trust in the clinician and the method, while still providing some variability of targets. Because the ultimate goal is motor learning, however, these blocks should become progressively shorter over time, and less frequent, until the child is relatively consistent in accuracy and can produce the target with a normal rate and varying prosody. At that point, the clinician begins to

Table 5. Example of a modified block practice schedule. Bold type indicates words for extra practice.

Target utterance	Practice Block 1	Practice Block 2	Practice Block 3	Practice Block 4	Practice Block 5	Practice Block 6	Practice Block 7[a]	Practice Block 8[a]	Practice Block 9[a]
Hi	**25–40[b] trials**			**25–40 trials**					**25–40 trials**
Bye		15–20 trials							
No			**25–40 trials**			**25–40 trials**			
Up					15–20 trials				
Eat							15–20 trials		
Mom								15–20 trials	

[a]Every target should be practiced for at least one block, with one or two targets practiced for slightly longer blocks, and at least one additional block. It is unlikely there will be time for nine blocks of practice in one session. This is just an example to show how the modified block practice may work. [b]This is an arbitrary number of trials that will vary depending on CAS severity, difficulty with particular target, and how long the child has been in Dynamic Temporal and Tactile Cueing therapy.

elicit one production of the word or phrase in response to a question or naming a picture. This is done randomly throughout the session, interspersed among blocks of practice on other targets. When the child has reached the clinician's chosen criteria on probe testing (discussed in the Measurement of Progress section) and has produced the target randomly with no cueing over at least two to three sessions, the target can be moved out of treatment and into a carryover phase.

Feedback

Feedback may be as simple as providing KR (e.g., "right" or "wrong"). Feedback can also be specific, giving the child more detail (KP, e.g., "your mouth is too open," "make your lips round"). Findings from the limb motor learning literature generally show that high-frequency and KP feedback facilitates acquisition but may negatively impact retention, whereas low-frequency and KR feedback enhances retention (e.g., Schmidt & Bjork, 1992; Winstein & Schmidt, 1990). Research is limited regarding feedback frequency in the treatment of SSDs and has resulted in mixed findings for both adults and children with CAS (e.g., Austerman Hula, Robin, Maas, Ballard, & Schmidt, 2008; Maas et al., 2012), suggesting that feedback frequency effects likely vary due to factors such as age, severity of speech deficits, and comorbidities.

In DTTC, feedback is provided very frequently and with KP at first, providing information about what is wrong ("your mouth is too open") and/or how to fix it ("close your mouth a bit") until the child becomes closer to movement accuracy, at which point frequency of KP is gradually reduced and KR is used and then faded. Although frequent feedback has been shown to reduce maintenance of performance in limb movement with healthy adults, it may be necessary at first to use frequent KP feedback for children, especially with severe speech deficits. Strand et al. (2006) showed maintenance of performance for children with CAS, in a design where KP and frequent feedback were used at first and faded as soon as possible. Wulf, Shea, and Matschiner (1998) also provided evidence to support the idea that high-frequency feedback may be beneficial for complex motor skills until the learner achieves some accuracy. Furthermore, Sullivan, Kantak, and Burtner (2008) reported that children and adults use feedback differently and suggested that, for optimum motor learning, children may need longer periods of practice with KP and gradually reduced frequency of feedback.

Elements Important to the Application of DTTC

The hierarchy and cueing methods designed for DTTC were developed to include a number of elements important to the acquisition and generalization of movement accuracy for speech. The inclusion of these elements was motivated by the literature on motor learning, imitation, and learning theory, as well as from clinical experience. In this section, six elements important to the acquisition and retention of movement accuracy for speech production and essential to the implementation of DTTC are described in order to enhance clinicians' understanding of the rationale for the DTTC strategies. Three of these elements were noted to be specific to DTTC: focusing on movements versus phonemes, intention to improve movement, and addressing proprioception. I also discuss supporting literature to draw clinicians' attention to maximizing a child's response to therapy, the importance of practice, and the use of imitation.

Elements Specific to DTTC

Focus on Movements Versus Phonemes

Consistent with the view that CAS involves impairment in the precision and consistency of movement, DTTC emphasizes the behavioral shaping of accurate movements.

That means, using auditory, visual, and tactile cues to facilitate movement accuracy at the level of the syllable or larger units (vs. an isolated sound) and the continued practice of those movements must occur only in the context of carefully selected speech stimuli. This focus is likely the element that most clearly distinguishes DTTC from many other treatments for SSDs. Unlike much of the therapeutic work done in pediatric SSDs, DTTC does not focus on improving the acquisition of phonology in a direct way. Rather, we are working to improve the inefficient processing involved in the sensorimotor planning and programming of volitional movements for speech, with the desired outcome being improved accuracy of movement for speech (resulting in improved sound production).

Students and clinicians are well trained in phonology and are accustomed to thinking in terms of "sound errors" and treating "sound" production. Phonemes, however, are mental categories, which are realized acoustically because of movements that are not static but continuous. They change based on the effects of co-articulation. The movement of the oral articulators changes the vocal tract shape and constricts the resonating sound source for the particular allophonic variations of the targeted sounds. Unlike phonemes and graphemes, which can be represented as segments, movements are not segmented during the syllable but involve movements of the articulators to form and then transition between vocal tract shapes. Therefore, DTTC emphasizes the movement itself (vs. the sound) as the focus of treatment. This emphasis is embodied in the decisions the clinician makes when devising lists of stimuli and choosing the timing and types of cueing to incorporate.

It is especially important to note that DTTC emphasizes the continuous movement transition for the elicited utterance and specifically avoids any segmentation of movement within the syllable (e.g., b-oy [bə.oɪ]). It may be tempting to think that, if we separate the individual "sounds" within the syllable, the production task will be made easier. While breaking down the child's production task may be helpful in treating some SSDs, it actually impedes progress for children with CAS as we are teaching the child two incorrect movements for the intended utterance. The movements for b-oy ([bə.oɪ]) and boy ([boɪ]) are not the same.

Intent to Improve Motor Skill

Research on motor learning has shown the importance of focusing the learner's attention to the intent to improve movement in order to be able to produce that movement without help at a later time (Badets, Blandin, & Shea, 2006; Schmidt & Lee, 2005). DTTC emphasizes focusing the child's intent to improve movement accuracy for specific speech goals. This is done primarily through the choice of words we use, such as letting the child know we will be working on "moving better" so talking will be easier (rather than "Let's work on our sounds"). We may start sessions with 30 s to 1 min of warm-ups where we draw attention to parameters of movement, making our jaw, lips, and tongue "tight" and "loose"; move fast and slow; or make some big versus little jaw movements. We provide specific feedback about movement ("oops, close your jaw a little") and often encourage them to "feel what your mouth is doing." These activities are very brief and done only to draw awareness to movement.

Addressing Proprioception

Proprioception is the unconscious and conscious perception of positions of body structures and movements of those structures in space. Proprioception occurs partly due to the role of proprioceptive receptors in combination with the cerebellum and vestibular system (Goetz & Pappert, 1999; Kandel, Schwartz, & Jessell, 1991). Observations of the types of difficulty children with CAS have in achieving specific spatial and temporal targets have led to questions whether this might be due to decreased use of proprioception. Although we do not have diagnostic procedures that allow its confirmation, this explanation seems intuitive and led to the inclusion of strategies in DTTC to address possible deficits in proprioception. First, if the child has had difficulty getting to an initial configuration, the clinician has the child stay in that initial articulatory configuration for a bit, to increase proprioceptive awareness by drawing attention to it, as well as giving the brain more time to process the "feel" of the position of oral structures prior to beginning to shape the movement through the syllable. Within the DTTC hierarchy, the initial simultaneous and repeated productions are produced slowly at first to facilitate more accurate movement and to allow more time for proprioceptive processing. Finally, the child is frequently reminded to focus on the "feel" of the movement, drawing his or her conscious attention to the movement.

Additional Treatment Elements

Practice

The motor learning literature emphasizes the important role of practice (e.g., Maas et al., 2008; Schmidt & Lee, 2005). (Note, however, that the conditions of that practice are important to the retention of the motor skill [Schmidt & Bjork, 1992], which is discussed in the Blocked Versus Random Practice section). The clinical literature in SSD treatment and motor speech disorders also emphasizes the importance of intensity of practice and provides empirical evidence for this (Allen, 2013; Edeal & Gildersleeve-Neumann, 2011; Rosenbek et al., 1973).

Intensity of practice can be considered from the standpoint of frequency per week, length of sessions, number of practice trials per session, and so forth (Warren, Fey, & Yoder, 2007). Most clinicians observe that frequent sessions provide quicker acquisition of skill, and this observation has been substantiated in the clinical literature (Namasivayam et al., 2015; Strand et al., 2006; Thomas, McCabe, & Ballard, 2014). Just as important as session frequency is the need to maximize response trials per session, as children producing higher numbers of practice trials per session demonstrate faster acquisition and better retention than those with fewer practice trials (Edeal & Gildersleeve-Newman, 2011). This much practice in a "drill" format,

while important, can be difficult to attain and poses potential problems in the implementation of DTTC. In order for learning to occur, the child must be paying attention to the feel and sound of their productions and the feedback being provided during practice. If the child has gone on "automatic pilot," just repeating without thinking about what they are doing, learning is not happening. (Likewise, if the clinician reduces attention and omits needed cueing, negative practice can occur, creating an additional burden for an already inefficient motor system.) In DTTC, the clinician should be on guard for this and, when it occurs, stop the activity and do some novel strategy, such as standing or putting the child's hands palm to palm with theirs as they continue practice, to bring back the child's conscious attention.

Helping a child focus and maintain attention, especially to a difficult task, is a common problem for clinicians. Therefore, traditional therapy is often constructed around fun games that may keep the child engaged. However, such games can take up precious therapy time, reducing the number of practice trials per session and taking the child's attention away from the clinician's face, both of which are discouraged in the treatment of CAS. Therefore, when implementing DTTC, clinicians are encouraged to use very quick reinforcers that keep the child engaged and looking at the clinician's face (e.g., the clinician may hold a whirring, visually stimulating toy right next to her face, which can be turned on after a number of trials; have a small ball ready to throw in a net or basket after a number of trials; put tokens in a can that lead to a prize). It is also helpful to "mix up" the child's position, for example, having them stand and take a step forward or backward after a number of trials; later having them sit on a small table; and then, later still, having them sit on a chair. "Changing it up" can bring back attention and create a more fun environment. The important thing is that the child should easily see the clinician's face (see Use of Auditory and Visual Modeling and Imitation section).

For some children, the clinician may have to try a number of reinforcers to find those that are truly appealing. At first, for younger or very inattentive children, the clinician may have to start by eliciting an imitative response for a word or syllable they have heard the child say and use a 1:1 schedule of reinforcement, moving to 2:1, then perhaps 4:1, and so on, until the child can produce a number of good practice trials between each reinforcement and can move on to novel stimuli selected by the clinician.

Use of Auditory and Visual Modeling and Imitation

Imitation is typically described as a complex behavior involving the reproduction of a behavior and often implies performing an act after seeing it done by another individual (Prinz, 2005). Providing a model prior to an imitative response has been reported to be an effective tool in teaching motor skill (Schmidt & Lee, 2005).

Auditory and visual modeling is at the core of IS approaches to therapy, including DTTC. The clinician frequently reminds the child to "watch my face" or "look at me" so that the child has repeated opportunities to observe the visual model while hearing the auditory model. In DTTC, this cue is faded as movement accuracy for the target word or phrase begins to improve. Previous experience with IS and the literature on imitation influenced the emphasis on visual and auditory imitation (vs. picture stimuli) used in DTTC. This section briefly describes support for the use of both auditory and visual imitation.

The role of auditory input is well known to be important in speech acquisition, and many studies have shown the effects of hearing loss during early speech development (e.g., Kent, Osberger, Netsell, & Hustedde, 1987; Rvachew, Slawinski, Williams, & Green, 1999). Models of speech production often include the role of auditory input to aid in formation of auditory–perceptual targets for speech output and point out the importance of auditory feedback in speech production (e.g., Baker, Croot, McLeod, & Paul, 2001; Van der Merwe & Steyn, 2018). Auditory perception has also been shown to play an important role in learning and fine-tuning motor speech plans (Shiller & Rochon, 2014).

Auditory verbal imitation has been shown to begin in infancy (Meltzoff, 1999). For example, Kuhl and Meltzoff (1996) showed infants listening to a particular vowel produced vocalizations resembling that vowel, demonstrating vocal imitation at that young age. Therapy for SSDs typically includes emphasizing the auditory perception of sounds and words. While DTTC emphasizes visual attention to the clinician's face more overtly than other methods for treating SSDs, auditory modeling and imitation are also an important part of the method.

Visual imitation plays an important role in treating apraxia of speech. Clinicians who have spent time working with both adults and children with apraxia of speech have observed that these individuals are more accurate in imitation of target utterances if they watch the clinician's face as they provide the verbal model. Visual imitation of the clinician's face is a key element of DTTC, and the use of picture stimuli is not recommended. Interestingly, this has never been empirically tested in the treatment of adult apraxia or CAS. However, there is literature to support the importance of visual imitation. First, imitation of facial gestures has been shown to occur in early infancy (Meltzoff & Moore, 1983), although the quality of visual facial imitation changes over time (Meltzoff & Moore, 1997). Although infants cannot see their own faces, they can use proprioception to monitor their own actions and even correct the imitative behavior (Meltzoff, 1999). Meltzoff (1999) also states that research on imitation suggests "a common coding for perception and production" (p. 389).

Studies have shown that observing a motor act facilitates subsequent performance of the act (e.g., Heyes & Foster, 2002; Wulf et al., 1999). In their comprehensive review, Wulf et al. (1999) note that observation allows development of a cognitive representation of the task and thereby facilitates subsequent practice trials. They also reviewed studies that showed observation and physical practice together were more effective than physical practice

alone. Kent (2004) reviewed evidence for cognitive–motor interactions, including observation. He noted there is increasing evidence that observing an act facilitates the subsequent performance of that act and "observing, imaging, and performing a movement are represented in a common neural circuit that reflects the cognitive–motoric integrity of learned movements" (p. 7).

While imitation is important in developing speech skill, children with CAS may become too reliant on the visual and auditory model. As therapy proceeds, children need to be able to rely less on imitation and become more independent in speech production. DTTC is designed, through both the temporal hierarchy (especially the delayed and spontaneous production levels of the hierarchy) and the fading of cues within each level, to help the child take increasing responsibility for the assembly and retrieval of motor plans independently.

Maximizing a Child's Response to Therapy

DTTC is a structured, clinician-directed therapy, yet the needs of any child on any day may warrant special consideration. The concepts contained in the capability-focus framework (Kwiatkowski & Shriberg, 1993, 1998), a treatment framework developed to address child-based factors that might account for differences among children in responses to therapy, have been helpful in the development of DTTC. *Capability* refers to a child's prognosis or potential for improvement in speech (based on performance on language and speech measures); includes any cognitive, linguistic, motor, or psychosocial risk factors; and takes into account the child's ability to use self-monitoring to establish and maintain learning. In the case of CAS, capability for speech acquisition may be determined by (a) administration of the Dynamic Evaluation of Motor Speech Skill, a dynamic motor speech examination (Strand & McCauley, 2019; Strand et al., 2013) that measures how easily a child benefits from cueing strategies, and (b) appraisal of concomitant deficits.

Focus includes attention, effort, and the motivation to practice and use feedback. In the case of DTTC, clinicians are encouraged to draw the child's attention particularly to the feel of the movement and to help the child develop motivation to improve movement accuracy. Kwiatkowski and Shriberg (1998) note that focus can be measured through dynamic assessment and observing the child's responses to learning trials. Therefore, the Dynamic Evaluation of Motor Speech Skill and the dynamic nature of DTTC provide ample ongoing assessment of focus.

In their description of the primary emphasis in the capability-focus framework, Kwiatkowski and Shriberg (1998) effectively summarize the importance of maintaining the active involvement of the child as therapy proceeds: "To obtain and maintain the child's active involvement requires clinicians to develop and administer a treatment approach that is constantly attuned to the child's changing learning needs" (p. 28). DTTC's emphasis on the "dynamic" aspect of therapy is consistent with such a notion. There is a fluid approach to moving up and down the temporal hierarchy and to adding and fading of cues within each level of the hierarchy. Furthermore, the clinician is encouraged to make other clinical decisions in order to respond flexibly to the child's day-to-day needs. For example, if the child has difficulty with imitation of the initial placement for the target movement transition, the clinician may add phonetic placement techniques before moving to the DTTC hierarchy. If a child has difficulty maintaining attention or effort for a half-hour session, or if the child is having a bad day, the clinician may choose to use shorter blocks of practice with more language or communication activities interspersed. Although not usually recommended in DTTC, it is sometimes necessary to start with short blocks of practice, gradually increasing to practice over the whole session.

Conclusion

DTTC is a treatment method designed for severe CAS. It is a bottom-up approach focused on the goal of helping the child improve neural processing (sensorimotor planning and programming) that is inefficient. The rationale for DTTC in general and the key elements important to its administration are supported by models and theories of speech motor control. Clinical decisions regarding amount of practice, number and structure of stimuli, organization of practice, and types and timing of feedback are based on PML in order to facilitate acquisition and retention of motor speech skill. The severity of CAS in the children for whom this method was developed, the complexity of speech movement compared to discrete limb movement, and the general challenges in working with young children did require some modification to those principles studied for discrete movements with adults.

A number of potential problems when using DTTC (e.g., difficulty of "drill"-type practice, repetition without learning, difficulty with sustained attention) have been discussed throughout this article, with suggestions for avoiding or managing them. Because DTTC requires the clinician to make many online clinical decisions, issues related to measurement of treatment fidelity are important to consider, although focusing on the key ingredients may provide a good structure for defining a checklist of observations of fidelity.

The treatment efficacy research for DTTC, to date, incorporates primarily single-subject design and typically with small sample sizes; however, there is at least some evidence across research labs for the use of DTTC with children with severe CAS (Baas et al., 2008; Strand & Debertine, 2000; Strand et al., 2006) and moderate CAS (Maas et al., 2012; Maas & Farinella, 2012). Continued research is needed across additional research groups and with larger sample sizes. For this research to make its fullest contribution, it is important that participants be well described and that clinical decisions regarding stimuli choice and organization of practice be well specified with the rationale provided. There are a myriad of questions still needing answers in the treatment of CAS and many children who will benefit from our answering them.

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