Examining the efficacy of complex clusters in real words and nonwords during the treatment of
speech sound disorders

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Abstract

This study compared the treatment efficacy of real words (RW) and non-words (NW) containing complex consonant clusters. Using a single-subject multiple baseline design, six children with speech sound disorders (SSD) (5;3 to 6;2) were split into two treatment groups (RW and NW). Children taught clusters in RWs had more accurate productions and greater generalization of their treatment target, while children in the NW treatment resulted in a greater decrease in error variants. Both groups demonstrated similar changes in their overall percent consonants correct and untreated cluster production accuracy. Thus, complex cluster targets in both RWs and NWs should be considered to be efficient and efficacious options when providing SSD treatment. Since children demonstrated widespread phonological change despite often lacking all cluster segments in their phonemic inventories, previous suggestions of complex cluster target selection may need to be revisited.

INTRODUCTION

The efficiency of treatment is a growing concern for speech-language pathologists (SLPs) who often have large caseloads and not enough time to adequately serve all of their clients. One group that is heavily represented on school caseloads is children with speech sound disorders (SSD). Children with SSD have a severely reduced consonant inventory, relative to their age-matched peers (Gierut & Morrisette, 2014). Along with their impairment in the production of speech, their ability to accurately create phonological (i.e. mental) representations of speech sounds is also arguably impaired. Thus, SSD is not just a lack of control over articulators but also indicates a disruption in phonological acquisition. With up to 25% of children between the ages of five and seven years having a SSD (Law, Boyle, Harris, Harkness, & Nye, 2000), providing effective treatment in a timely manner can help SLPs successfully manage their caseloads.

Lexical influences on phonological learning. SLPs are typically trained to address specific sounds in error during the remediation of a child's SSD. However, the words that contain those target sounds should also be carefully considered, as important interactions between phonological and lexical development have been identified (Stoel-Gammon, 2011), which may then impact the effectiveness of a given SSD treatment approach. In other words, taking into account the lexical characteristics of a word (e.g. word frequency), as well as its corresponding phonological properties, may influence the degree of change in a child's phonological system.

Three lexical variables are commonly discussed in the literature: word frequency, phonological neighborhood density, and age of acquisition (AoA). Briefly, word frequency refers to the number of times a word occurs in a written or spoken language corpus while AoA refers to the age at which a word enters a child's vocabulary (Sosa & Stoel-Gammon, 2012). While

considered to be separate lexical variables, there is often a strong relationship between word frequency and AoA, in that many high frequency words are also acquired early in development. Both variables contribute to the familiarity of a word, which can impact the ease with which a word is both accessed and produced (Garlock, Walley, & Metsala, 2001; Sosa & Stoel-Gammon, 2012). Phonological neighbors are often defined as words that differ from one another in terms of the addition, deletion, or substitution of a single phoneme (Luce & Pisoni, 1998; Sosa & Stoel-Gammon, 2012). Thus, neighborhood density refers to the number of phonological neighbors a word has, so that some words with many neighbors are considered to be high in density while words with few neighbors are considered to be low in density.

Current models of phonological representation specifically address the phonological/lexical interaction by identifying two levels of representation (Gupta & MacWhinney, 1997; Luce, Goldinger, Auer, & Vitevitch, 2000; Sosa & Stoel-Gammon, 2012; Storkel & Morrisette, 2002). The lexical representation corresponds to a word as a whole unit (e.g. /dag/ for “dog”), while the phonological representation corresponds to the individual sounds or sound sequences that make up the word (e.g. /d/, /ɑ/, /g/, /dɑ/, /ag/). The lexical representation may play a role in how words are perceived and produced, while the phonological representation may affect how a (spoken) word is encoded and processed. Thus, the type of lexical representation used in the treatment of SSD may affect what type of learning and/or generalization occurs during the creation of a phonological representation.

All three lexical variables have been examined in typically developing children, with the overarching finding being that manipulating them could greatly affect children’s performance on various tasks. More specifically, high frequency words, words from dense phonological neighborhoods, and early-acquired words have been found to improve children’s acquisition,

perception, and/or production of words (Garlock et al., 2001; Metsala, 1997; Munson, Swenson, & Manthei, 2005; Sosa & Stoel-Gammon, 2012; Stoel-Gammon, 2011; Storkel, 2004; Storkel, Maekawa, & Hoover, 2010). Moreover, there is a strong relationship between these three lexical variables in that high frequency words from dense phonological neighborhoods are acquired earlier in development than low frequency words that are also low in density (Storkel, 2004).

Importantly, these lexical variables have also been manipulated in different ways during the treatment of SSD (also referred to as phonological disorder). For example, a series of studies by Gierut, Morrisette, and colleagues (Gierut & Morrisette, 2012b, 2014; Gierut, Morrisette, & Champion, 1999; Morrisette & Gierut, 2002) has found that words coming from dense phonological neighborhoods can improve speech treatment outcomes, but only if certain conditions are met, such as when input cues converge (i.e. phonologically dense words must also be high frequency and early acquired) (Gierut & Morrisette, 2012b) or when phonologically dense words precede or prime words used in treatment (Gierut & Morrisette, 2014). In addition, it has been found that late-acquired words can induce larger amounts of phonological generalization due to treatment than do early-acquired words (Gierut & Morrisette, 2012a).

With the end goal of speech treatment being to create widespread change in children's sound systems, it is important to consider whether certain lexical variables of treatment words might induce more phonological generalization than others. However, given that word frequency, AoA, and neighborhood density are highly correlated (Storkel, 2004), it can be difficult to isolate one lexical variable from the others. One option for controlling the lexicality of words is to compare real words (RWs) with nonwords (NWs). More specifically, RWs and NWs will always differ in terms of their word frequency (and arguably AoA), in that RWs can be either high or low in their

frequency of occurrence in a language, but NWs are always low in frequency, given their non-occurrence in the language (by definition).

Only a few comparisons of RWs and NWs in the treatment of SSD have been completed, with the overarching finding that both types of words could induce phonological change in treatment, albeit in different ways (Cummings & Barlow, 2011; Gierut & Morrisette, 2010; Gierut, Morrisette, & Ziemer, 2010). For example, Gierut and colleagues (2010) found that children treated with NWs demonstrated faster phonological change than did the children treated with RWs, though both groups demonstrated comparable levels of production accuracy two months post-treatment. Similarly, Cummings and Barlow (2011) found that children who were treated with NWs had larger reductions in the number of sound substitutions produced for their treatment target, indicating that NWs helped the children better establish a phonemic category for their treated sound. However again, both types of treatment resulted in similar amounts of generalization to untreated sounds. Thus, it appears that RWs and NWs could be comparably effective treatment targets.

Complexity treatment for SSD. All of the above studies comparing RWs and NWs targeted a single consonant (e.g. /t/) in treatment. However, another way to potentially improve treatment efficiency and effectiveness is to address the phonological complexity of the treatment target. Sounds follow a hierarchy of development; meaning that some sounds are earlier-developing and others are later-developing (Goldman & Fristoe, 2000; Smit, Hand, Freilinger, Bernthal, & Bird, 1990; Templin, 1957). Later-developing sounds can be defined as complex sounds, as they require a higher level of articulator coordination and phonological knowledge. The complexity approach to treatment suggests that training complex structures will promote generalized improvement of simpler, linguistically related structures (Gierut, 2001, 2007; Thompson, 2007).

Thus, by exposing children to the higher-ordered, more complex elements, lower or secondary elements will fall into place and generalization will occur. In other words, for speech treatment, by targeting more complex sounds or sound combinations, less complex sounds and sound combinations might be positively affected by treatment as well (Dyer, Santarcangelo, & Luce, 1987; Gierut, Morrisette, Hughes, & Rowland, 1996; Powell, 1991; Powell, Elbert, Miccio, Strike-Roussos, & Brasseur, 1998).

While much of the phonological complexity research has focused on consonant singletons, consonant clusters are even more complex structures. Similar to singleton consonants, two- and three-element clusters have a hierarchical order of acquisition (Gierut & Champion, 2001; Ingram, 1976; Smit, 1993; Smit et al., 1990; Smith, 1973; Templin, 1957). Moreover, clusters also follow a governing system that defines permissible sequences of sounds within syllables. The Sonority¹ Sequencing Principle (SSP) states that syllables gradually increase in sonority toward the nucleus (i.e. vowel) of the syllable and fall or remain in sonority after the nucleus (Barlow, 2004; Clements, 1990; Gierut, 1999). Thus, using the SSP, the organization of clusters in terms of complexity is possible, with more complex clusters assumed to have a smaller sonority distance (SD) (figure 1).

<insert figure 1 about here>

While most English clusters follow the SSP, there are a few select clusters in English that violate sonority sequencing: the /s/ + stop clusters, such as /sp/, /st/ and /sk/. While onset clusters should rise in sonority, /s/ + stop clusters fall in sonority. The term “adjunct” has been used to differentiate the /s/ + stop clusters that violate the SSP from all other true clusters (Gierut, 1999).

¹ Sonority refers to the resonance property (loudness) that a speech sound possesses as compared to other sounds with the same length, stress, and pitch.

To explain, for the true cluster /tɹ/, the singletons /t/ and /ɹ/ each occupy a timing slot and they have a branching structure at the level of the onset. In comparison, for the adjunct /st/, there is no branching onset because /s/ is immediately dominated by the syllable node. Given the unusual patterning of /s/ clusters, it can be assumed that the /s/ is outside the onset constituent and thus is viewed as an “adjunct” to the syllable (Barlow, 2004). In addition to the two-element /s/ + stop clusters, the three-element clusters are made up of both an adjunct /s/ and a true branching cluster.

While a variety of studies have described children’s cluster productions (Allerton, 1976; Barton, Miller, & Macken, 1980; Catts & Kamhi, 1984; Chin & Dinnsen, 1992; Greenlee, 1974; McLeod, Doorn, & Reed, 1997; Menyuk & Klatt, 1975; Smit, 1993), only a few studies have examined their clinical efficacy in children with SSD. For example, Powell and Elbert (1984) investigated whether three children with SSD (4;4 to 6;3) taught to produce complex, later developing fricative + liquid clusters (i.e. /fɹ/, /sɹ/, and /ʃɹ/) would exhibit generalization patterns that differed from those of three children taught to produce less complex, earlier-developing stop + liquid clusters (i.e. /tɹ/, /bɹ/, /gɹ/). More specifically, children were taught to produce minimal pair contrasts at a syllable level for each of their three target clusters (e.g., /ti/-/tɹi/, /bu/-/bɹu/, /go/-/gɹo/). After approximately nine months of treatment, both groups of children demonstrated similar levels of accuracy production, regardless of which clusters were targeted during treatment. Moreover, generalization occurred to both the treated and untreated cluster categories, implying that some system-wide generalization had occurred; thus establishing early evidence for the efficacy of consonant cluster treatment (Powell & Elbert, 1984).

Gierut (1999) varied the complexity of treatment clusters to examine differences in phonological change. Three children were taught less complex clusters with greater sonority distances (i.e. /kl/, /kw/, /pɹ/) while three other children were taught more complex clusters with smaller sonority distances (i.e. /fl/, /fɹ/, /bl/). Each cluster was presented in word-initial position in 15 nonwords (NWs) in a storybook format. Participants taught less complex clusters (e.g. /kl/) exhibited less system-wide phonological generalization than the children who were taught more complex clusters (e.g. /fl/) (Gierut, 1999). Thus, children taught more complex clusters with greater sonority distances demonstrated greater learning than those taught the less complex clusters.

Gierut and Champion (2001) conducted the only study examining the use of three-element clusters in speech treatment. Eight children were treated on four different clusters – two children per cluster (/spl/, /skɹ/, /spɹ/, or /skw/). Each target cluster was presented in the word initial position in 16 NWs in a storybook format. While the children showed improvement in their productions of their treated words, they did not demonstrate any generalization to untreated words containing three-element clusters. However, generalization occurred to untreated singletons, affricates, and two-element clusters for all children. Importantly, the singletons acquired were not necessarily subsets of the treated three-element cluster. Given these patterns of learning and generalization, three-element clusters could be an efficient and effective treatment target choice, though it was interesting that the children were unable to accurately produce their treated cluster in untreated words.

The present study. Much of the prior complexity research involving both consonant singletons and clusters has used NWs as treatment targets. NWs are often used so that lexical and

phonological variables (e.g. frequency, familiarity, age of acquisition, density, etc.) can be easily controlled. Moreover, NWs avoid the potential biases associated with previous life experience and semantics (Bryan & Howard, 1992; Leonard, Newhoff, & Mesalam, 1980). Because children do not have lexical representations for NWs, it may be easier to establish new knowledge with them in treatment, as opposed RWs, which already have lexical representations meaning that their respective phonological representations must then be changed.

The use of NWs in treatment can also allow children to focus on the articulation (Hoffman, Schukers, & Daniloff, 1989) of a targeted sound; that is, due to their non-meaning in the English language, NWs only involve sublexical processing, rather than also involving lexical processing. By presenting children with entirely new sound combinations (i.e. NWs) more change in a child's sound system could occur because the child will not have had any prior experiences with the treatment words. In other words, NWs may help reduce cognitive processing demands, which may allow for more automatic sound and word productions.

While NWs can be useful in treatment, it is questionable how useful these treatment targets are to children's learning, especially because children with SSD are often at risk for academic difficulties in language, reading, spelling, and/or math (Bird, Bishop, & Freeman, 1995; Clarke-Klein & Hodson, 1995; Hoffman, 1990; Hoffman & Norris, 1989; Kamhi & Catts, 1986; Lewis & Freebairn, 1992; Webster & Plante, 1992). The obvious alternative to using NWs in treatment is to target RWs. RWs are functional treatment targets, as children potentially hear and practice these words in everyday life, which might induce greater phonological change than unfamiliar words (Gierut et al., 2010; Gupta & MacWhinney, 1997; Luce, Pisoni, & Goldinger, 1990; Storkel & Morrisette, 2002). Moreover, it is possible that RWs could induce greater phonological change due to their lexical nature. That is, the additional linguistic (e.g. semantic, syntactic,

pragmatic) information associated with a RW, as well as the phonological and lexical characteristics, may improve a child's performance in treatment.

Given that much of the prior research on complexity, and complex cluster treatment in particular, has used NWs, it is important to know whether the findings would still hold when RWs containing clusters are treatment targets. Thus, the present study compared RWs and NWs in the treatment of complex consonant clusters in children with SSD. Based on previous studies comparing RWs and NWs in consonant singleton treatment (Cummings & Barlow, 2011; Gierut et al., 2010), it was possible that similar phonological change would be observed in both groups of children. Alternatively, it was a possibility that the higher frequency RWs might induce greater phonological change than would NWs that have null frequency values (Storkel & Morrisette, 2002).

In order to evaluate phonological change, the present study used a variety of measures to gather converging evidence of the effectiveness of the treatment procedures. Children's production of their treatment target in treated and untreated words was measured to assess the learning of a specific treatment target. Moreover, given that the complexity research body suggests that while a treated target might not generalize, less complex targets might still be mastered, other measures were used to assess system-wide phonological change. These measures included overall consonant accuracy change, as well as the generalization of untreated clusters and singletons.

Finally, the relative consistency of children's error substitutions was examined since previous studies have observed varying levels of production consistency across different types of words (Cummings & Barlow, 2011; Sosa & Stoel-Gammon, 2012). For example, Sosa and Stoel-Gammon's (2012) observed that young children produced late-acquired words with greater proximity (i.e. consistency) in relation to an adult target than early-acquired words. This late

AoA effect was interpreted in terms of the interaction of a child's phonological system and the addition of new words. It was hypothesized that if a word entered a child's lexicon during a more advanced stage of phonological development, it would be more likely to conform to new developments in the child's phonology, making it more accurate than previously existing words that might not yet have been affected by recent changes in the phonological system (Sosa & Stoel-Gammon, 2012). Thus, examining the variants of children's productions of their targeted clusters could provide additional evidence for the usefulness of RWs or NWs in treatment. Moreover, it was possible that children who had more variable error patterns prior to the onset of treatment would respond differently to treatment than did children who had consistent error patterns (Dodd & Bradford, 2000; Forrest, Elbert, & Dinnsen, 2000; Tyler & Lewis, 2005; Tyler, Lewis, & Welch, 2003). Thus, a thorough analysis of the two types of treatment would not have been complete without the inclusion of an error analysis.

In sum, the present study adds to the body of research that evaluates the effectiveness of the treatment of complex cluster targets. Two primary questions were addressed: 1) Will teaching children to produce a complex consonant cluster in RWs or NWs lead to more learning and generalization of a treated cluster? and 2) Will cluster treatment with RWs or NWs lead to greater system-wide phonological change?

METHOD

Experimental design. A single-subject multiple baseline design, in which every child served as his/her own control, was used in this treatment programme (Dinnsen & Gierut, 2008; McReynolds & Kearns, 1983; McReynolds & Thompson, 1986). This design has been used effectively in many different types of treatment studies involving children with speech sound disorders (SSD) (Cummings & Barlow, 2011; Gierut, 1999; Gierut & Champion, 2001; Gierut,

Elbert, & Dinnsen, 1987; Gierut et al., 1996, 2010; Gierut & Morrisette, 2010, 2011, 2012a, 2012b, 2014; Morrisette & Gierut, 2002; Powell et al., 1998). Following procedures for this design, the children with SSD were randomly assigned to one of two treatment groups: real words (RW) or nonwords (NW). Every child was evaluated in a baseline period in which no treatment was provided, followed by up to twelve sessions of speech treatment.

Each child first completed full assessments using the Assessment of English Phonology (AEP; appendix 1) (Barlow, 2003) and the Modified Onset Cluster Probe (MOCP; appendix 2). The AEP sampled all English sounds in each of their viable word positions at least five times. The MOCP was based on a previously published cluster probe (Gierut, 1998)² and was created to target all English two- and three-element clusters in word-initial position in 4-6 separate occurrences. In both assessments, children's spontaneous word productions were elicited using an electronic picture naming task and were digitally recorded using an Olympus Digital Voice Recorder (DS-2).

Subsequent baselines consisted of shorter baseline AEP probes that specifically targeted the singleton phonemes of each child's target cluster, as well as an abbreviated MOCP that targeted each child's treated cluster. Baseline measures were taken in the two to three sessions prior to the initiation of treatment. For example, a child completing two baselines would complete two baseline measures in separate sessions for one week prior to the beginning of treatment. For the post-treatment assessment, complete AEP and MOCP assessments were administered approximately two weeks after treatment was finished.

Participants. Six children (1 female; ages 5;3 to 6;2) with functional SSD were recruited to participate in this summer speech treatment programme. Three children were randomly assigned

² Some of the word targets on the MOCP were different than those on the Gierut (1998) probe, and all of the pictures used to elicit the word productions were different.

to the NW treatment condition (Children 11-13) and three children were randomly assigned to the RW treatment condition (Children 14-16). All children met the following entry criteria (table 1):

<Insert table 1 about here>

- Residency in a monolingual English-speaking household;
- A maximum standard score of 75 on the Goldman-Fristoe Test of Articulation – 2 (Goldman & Fristoe, 2000);
- Hearing within normal limits as determined by a standard audiometric screening (American National Standards Institute, 1991);
- An oral-peripheral mechanism exam completed within normal limits (Robbins & Klee, 1987);
- Nonverbal cognitive skills within normal limits (standard scores between 85 and 115) as assessed by the Brief IQ Screener on the Leiter International Performance Scale – Revised (Leiter-R) (Roid & Miller, 1997);
- Receptive vocabulary skills within normal limits as assessed by the Peabody Picture Vocabulary Test-4 (PPVT-4) (Dunn & Dunn, 2007).

Highly-trained transcribers used the International Phonetic Alphabet (IPA) to narrowly transcribe all speech samples. Based on these transcriptions, the data were organized for standard descriptive phonological analysis according to target sound/cluster and word position (Dinnsen, 1984). Every child had a reduced consonant inventory, excluding a minimum of two target English sounds from their respective phonemic inventories (table 2). Sounds excluded from the inventory were identified based on extensive phonological probe measures using the AEP

(Barlow, 2003). Phonemic status of a sound was established following the criterion of two unique sets of minimal pairs (e.g. 'sing'-'ring' or 'run'-'rub'), regardless of whether they were correct relative to adult production (Gierut, Simmerman, & Neumann, 1994).

<Insert table 2 about here>

Cluster production was measured by the MOCP. The phonetic status of a cluster was established by following the criterion of at least two unique productions of a cluster in word-initial position (Dinnsen, Chin, Elbert, & Powell, 1990; Morrisette, Farris, & Gierut, 2006). All children in this study excluded at least 10 clusters from their phonetic inventories (tables 3 & 4).

In addition, the minimum sonority distance (SD) of each child was also calculated following the suggestions of Morrisette and colleagues (2006). Children were given credit for a sonority valued if there were two occurrences of a cluster with that value. Once all the clusters were addressed, the sonority differences were examined in order to determine which cluster group had the smallest sonority difference (e.g. SD 2 is the smallest, while SD 6 is the largest), which was then declared the child's minimal sonority distance (tables 3 & 4). Children in the NW treatment group had minimum sonority distances ranging from 2-4, while all three children in the RW treatment group had minimum sonority distances of 2.

<Insert table 3 about here>

<Insert table 4 about here>

Stimuli. Both treatment conditions used a storybook format for presenting the treatment words, RW or NW. Similar to previous studies (Cummings & Barlow, 2011; Gierut, 1990, 1991, 1992; Gierut & Morrisette, 2010; Gierut et al., 1996), the story presentation ensured that the children in the RW condition understood the RWs; for those in the NW condition, the storybook

format assigned lexical meaning to the NW (see appendix 3 for an example of the /stɪ/ story used in the programme).

Given that the goal of this study was to compare RWs and NWs, the treatment targets differed in their lexicality or word frequency (table 5). The values from Kučera & Francis (1967) were used to determine whether the treatment targets for the current study were high or low in frequency. These values were gathered from the University of Washington St. Louis (written and adult) word frequency database, which was based on Kučera and Francis' (1967) written word database (<http://128.252.27.56/Neighborhood/Home.asp>). A word with a frequency score of 100 or higher was considered high frequency.

Previous studies directly comparing RWs to NWs in consonant singleton treatment (Cummings & Barlow, 2011; Gierut et al., 2010) were able to tightly control the word frequency of their treatment targets due to the large number of words that began with a given consonant. Unfortunately, the present study was somewhat limited in the number of RWs that had high frequency values. As a result, some of the highest frequency words containing each cluster were selected for this study, with the additional words being selected based on their ability to fit into the treatment stories. Thus, not all of the RWs had frequency scores greater than 100. Alternatively, due to their non-occurrence in English, all NWs had word frequency scores of 0, meaning that there was still a large word frequency difference between the two types of treatment words.

Another lexical variable that is similar, but distinct, from word frequency is Age of Acquisition (AoA); both are thought to contribute to the overall familiarity of a word. Given the relationship between frequency and AoA, it was not unexpected that the two types of treatment words also differed in terms of their AoA (table 5). Using the extensive AoA database of over

30,000 English words created by Kuperman and colleagues (<http://crr.ugent.be/archives/806>), it was determined that all the treatment words in the present study, other than throughout, are typically acquired by the age of 8 years of age (Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2012), while again NWs are not acquired at any point in development.

Due to this treatment study's focus on including words with clusters, other lexical and phonological variables, such as phonological neighborhood density and phonotactic probability (i.e. phoneme and biphone probabilities), were not specifically controlled³, but the two types of stimuli did not significantly vary along these dimensions (table 5). Independent sample t-tests for the neighborhood density and phonotactic probability measurements revealed that there were no significant differences between the two sets of treatment stimuli: neighborhood density ($t(18) = 0.642, p > .52$), phoneme probability ($t(18) = -0.418, p > .68$), and biphone probability ($t(18) = -0.579, p > .57$). Thus overall, all of the words were low in density with relatively rare sound sequences, which is consistent with the findings of Storkel and Morrisette (2002) who reported that low-density words are typically composed of rare sound sequences.

<Insert table 5 about here>

Clusters used in treatment. Every child's treatment programme targeted a single complex cluster that was excluded from his or her phonetic inventory. Four children received treatment on the three-element cluster, /stɪ/, and two children received treatment on the two-element cluster, /θɪ/, that had a sonority distance of three. Five of the six children were stimulable for all of the

³ The phonological neighborhood density measurements were calculated using the Washington University in St. Louis Speech and Hearing Lab Neighborhood Database on-line calculator at: <http://128.252.27.56/Neighborhood/Home.asp>. Phonotactic probability refers to the relative frequency with which individual sounds and sound sequences occur in syllables and words (Jusczyk & Luce, 2002). Phonotactic probability measurements (i.e. phoneme and biphone probabilities) were calculated using the on-line Phonotactic Probability Calculator at: <http://www.people.ku.edu/~mvitev/PhonoProbHome.html>.

singletons that comprised their target cluster; one child was only stimulable for one of the two singletons in his two-element cluster (table 1).

Both the RW and NW treatment words (table 5) were introduced within a storybook context. A licensed and certified SLP read all stories in-person during the treatment sessions. Colour picture cards made from illustrations in each story were introduced to the children in conjunction with the five treatment words. These were used during treatment to elicit the children's word productions.

Treatment Procedure. Treatment was delivered in two phases: Imitation and Spontaneous Production. This treatment protocol was chosen in order to remain consistent with treatment protocols that have been used in previous studies (Cummings & Barlow, 2011; Gierut, 1992; Gierut & Morrisette, 2010; Gierut et al., 1996; Morrisette & Gierut, 2002). Treatment was provided twice weekly for 1-hour sessions, for a maximum of 12 treatment sessions over the course of seven to nine weeks during the university's summer clinic session.

Imitation Treatment Phase. During the Imitation phase of treatment, each child repeated the clinician's verbal model until either achieving a pre-established performance-based or time-based criterion whichever came first. Specifically, Imitation treatment continued until a child maintained 75% accurate production of the treated cluster as a whole over two consecutive sessions (i.e. performance-based criterion) or until five consecutive sessions were completed (i.e. time-based criterion). None of the children achieved the 75% accuracy criterion; thus, each child completed all five of the Imitation treatment sessions.

The overall focus of the Imitation sessions was to teach children to produce the cluster as a whole unit (2- or 3-elements). Each Imitation session began with the clinician reading to the child his selected treatment story during which each child was exposed to his/her treatment

words during the storybook reading.⁴ Story time was followed by five to ten minutes of direct placement and sound-shaping therapy during which each child was given verbal, tactile, and physical cues to help elicit each phoneme of the target cluster. The direct placement techniques were used because the children had some difficulty correctly producing the singleton sounds contained in their clusters. Thus, the individual segments were discussed separately.

Another technique that was used during the Imitation phase was segmenting the clusters (and the rest of the word) into various groupings of separate and combination sounds. The sound segmentation was used to teach the children the correct sequence of sounds in their clusters. This was typically done by either lengthening the fricative component of the clusters (/s/ or /θ/) or by adding a vowel schwa (/ə/) between the cluster's phonemes, essentially adding an extra syllable to the word. To clarify, in some segmentation activities for the three-element cluster, the combination of the first two consonants was emphasized, while in other productions, the combination of the second two consonants was emphasized; thus, both the adjunct and true cluster portions of the 3-element cluster were targeted separately and together. For example, instead of the child saying, "straw", he said, "stuh-rah" or "sss-trah". For the two-element cluster, sometimes the cluster was produced as a whole unit, other times the two consonants were separated. For example, instead of the child saying, "threw", he produced, "thuh-rew".

The remainder of each session was child-dependent, typically consisting of drill-play activities of the child's choice. Each targeted word was associated with a single picture from the story that broadly represented what the word meant, especially within the context of the story.

⁴ To be clear, the clinician never explicitly taught the children what each of the words meant, such as in their semantic definition and syntactic use. It was assumed that the children would indirectly learn about the meaning and use of the words through their appearances in the story.

On average, 92 responses (range 46-147) were elicited from each child, per condition, per session during the Imitation phase of treatment.

Spontaneous Production Treatment Phase. During the Spontaneous Production phase of the treatment, each child produced the treated cluster without a model. In other words, the target words were spontaneously elicited by having the children name pictures, label objects, etc. in drill-play activities. This phase of treatment continued until the child maintained either a performance-based criterion of 90% accuracy production of the treated cluster as a whole over three consecutive sessions, or a time-based criterion of seven sessions, whichever came first. None of the children achieved 90% accuracy for three consecutive sessions; thus, they all completed all seven of the Spontaneous Production treatment sessions. On average, 111 responses (range: 70-198) were elicited from each child, per condition, per session during the Spontaneous Production phase of treatment.

Reliability Transcription. Every pre- and post-treatment assessment session was digitally recorded with an Olympus Digital Voice Recorder (DS-2). Each audio sample was then digitally transferred to a PC laptop for transcription using a speech recording computer program, Adobe Audition®. Highly trained and blinded research assistants used the International Phonetic Alphabet (IPA) to narrowly transcribe all speech samples. Based on these transcriptions, the data were organized for phonological analyses according to target sound/cluster and word position. Approximately 30% of each child's AEP and MOCP speech samples were reliability-checked by a second transcriber; these speech samples were compared for point-by-point consonant agreement that was required to reach an agreement threshold of 85% for each sample. If this threshold was not reached, the speech sample in question was re-transcribed until two

transcribers reached the designated threshold. Overall, the transcriber reliability was 89% (range: 85-96%).

Treatment data was measured on-line by the attending clinician and accuracy of the entire cluster in each targeted word was scored as either being correct or incorrect. The second author administered the treatment and assessment sessions for Child 12 and Child 15. The first author administered all treatment and assessment sessions for the other four children, and observed all of the sessions of Child 12 and Child 15. Given that the first author was directly and/or indirectly involved in all children's assessment and treatment sessions, the treatment procedures were similar for all children.

Dependent variables and data analysis. The dependent variables in this study directly addressed the study's two main questions. One line of analysis examined children's learning and generalization of their treated cluster: Did speech treatment involving RWs lead to greater phonological change in a treated cluster than does NW treatment? These dependent variables included: learning during treatment and variability in sound substitutions for the treated cluster.

The second line of analysis examined the greater system-wide phonological change that occurred due to the treatment of a consonant cluster: Did learning to produce RWs with complex clusters lead to more phonological change than learning to produce NWs with clusters? These dependent variables included: overall change in Percent Consonants Correct (PCC), production accuracy change of untreated clusters, and inventory (segmental and cluster) change/additions. The descriptions of each variable are presented below.

Learning during treatment. As discussed by Gierut and Champion (2001), learning during treatment is relevant to establishing treatment effectiveness. Learning curves were created to track the production accuracy of the targeted cluster longitudinally during pre-treatment baseline

sessions, the two phases of treatment (Imitation and Spontaneous Production), as well as the child's production of the treated cluster during the two-week post-treatment MOCP assessment. Clusters were only judged to be correct if all elements of the cluster were produced in a manner similar to that of a healthy adult in the ambient language (i.e. lengthened sounds, slightly distorted productions, and so forth, were judged to be incorrect). It is important to point out that treatment effectiveness can only be measured effectively in conjunction with pre-treatment baseline measures. Thus, stable and ideally very low, pre-treatment production measures are vital to demonstrate learning during treatment.

Variability in sound substitutions for the treated cluster. The Error Consistency Index (ECI) was computed to measure the overall consistency of error substitutions within a child's phonological system (Tyler et al., 2003). In the present experiment, the ECI was a raw number that was calculated by summing the total number of different substitutions that each child made for his/her specific treated cluster on the MOCP. That is, the entire cluster was measured for variability; with the ECI referring to the total number of different ways each child produced his/her targeted cluster as a whole. The ECI was calculated both pre-treatment (taking into account any substitutions the child made for each cluster across the 2-3 baseline probes) and at the two-week post-treatment MOCP session. Correct productions of the target cluster were included in the ECI raw numbers and analyses; thus, the ideal ECI number was 1.0. Given that the number of cluster substitutions varied across children, the proportion change from pre-treatment to post-treatment was the best indicator of error variability modifications that occurred in conjunction with treatment.

Percent Consonants Correct (PCC). The PCC measure (e.g. (Shriberg, 1993; Shriberg, Austin, Lewis, McSweeney, & Wilson, 1997; Shriberg & Kwiatkowski, 1982) can be considered

to be a reflection of overall change in the children's phonological systems. The PCC was calculated by identifying the number of consonants the child produced correctly out of approximately 690 (the total number of consonants contained in the 256 words on the AEP). The Logical International Phonetic Programs 2.02 (LIPP) (Oller & Delgado, 1999) PC computer transcription programme was used in PCC calculation, in which each consonant was point-by-point identified as being correct or incorrect in relation to its target phoneme. Sounds were only counted as correct if they were produced in a manner similar to that of a healthy adult in the ambient language (i.e. lengthened sounds, slightly distorted productions, and so forth, were judged to be incorrect). This was especially important to ensure that the children were producing correct and adult-like productions (i.e. not distorted productions) of both /s/ and /ʃ/. PCC scores for both the pre-treatment and two-week post-treatment AEP probes were calculated. A significant change in PCC was identified if children demonstrated at least a 10% change in their PCC scores from the pre-treatment to the two-week post-treatment AEP, as per the assumptions of single-subject designs (e.g. McReynolds & Kearns, 1983).

Generalization to untreated consonant clusters. Using the same procedures as Gierut and Champion (2001), generalization to untreated clusters was measured in terms of percentage of production accuracy change from pre- to post-treatment. Similar to the PCC measures described above, clusters were only considered to be correctly produced if all elements in the cluster (two or three consonants) were produced in a manner similar to that of a healthy adult, with no distortions, sound lengthening, etc. Clusters were divided into their sonority distance groups, and production accuracy was calculated separately for each cluster sonority group (figure 4). The clusters that were present in each child's pre-treatment cluster inventory, as well as the additional clusters that were added post-treatment, are also presented in tables 3 and 4. Generalization of a

cluster sonority group was identified if children demonstrated at least a 10% change in their production accuracy from the pre-treatment to the two-week post-treatment MOCP, as per the assumptions of single-subject designs (e.g. McReynolds & Kearns, 1983).

RESULTS

Will teaching children to produce a consonant cluster in RWs or NWs lead to more learning and generalization of that cluster?

Learning during treatment. Beginning with the NW treatment data presented on the left side of figure 2, it can be seen that for all three children there was 0% accuracy of the treated cluster during the two to three pre-treatment baseline sessions. Given most of the children's prior treatment history, this stable baseline prior to the onset of treatment demonstrates the children's inability to accurately produce their selected treatment targets. Once treatment began, there were some differences in their learning curves. Child 11's progress was somewhat sporadic, while Child 12 and 13 both demonstrated steady increases in accuracy production, though the latter's progress was initially protracted. The RW treatment data on the right side of figure 2 demonstrate two different patterns of learning. Child 14's accuracy did not change from baseline levels throughout treatment. Alternatively, both Child 15 and 16 demonstrated steady increases in the production accuracy of their treated clusters. Comparing across groups, there is some indication that the use of RWs in treatment led to greater and more consistent treatment gains.

<Insert figure 2 about here>

Variability in sound substitutions for the treated cluster. Prior to the start of treatment, the number of substitutions for the treated cluster varied from two to eight different "cluster" productions (table 6). Post-treatment children's substitutions ranged from one to five different "cluster" productions. In the NW condition, all three children demonstrated decreases in the

number of cluster substitutions. Overall, there was less change in the RW condition, as only two of the children demonstrated decreases. The average percentage of sound change for the three children in the NW condition was 43%, while the percentage of change for the children in the RW condition was only approximately 30%. Thus, these ECI analyses suggest that using NWs in treatment may lead to greater decreases in a treated cluster's production variability.

<Insert table 6 about here>

Will cluster treatment with RWs or NWs lead to more widespread phonological change?

Percent Consonants Correct (PCC). The children's pre- and post-treatment PCC scores, as well as the change in accuracy, are presented in figure 3. Two children in each treatment condition demonstrated at least a 10% gain in their PCC values. Thus, these PCC measurements suggest that both treatment conditions elicited similar amounts of phonological change across all untreated consonant singletons.

<Insert figure 3 about here>

Generalization to untreated consonant clusters. The change in production accuracy for the children in the NW group varied extensively, as one child demonstrated at least 10% gains in all seven sonority groups (Child 12), one child demonstrated 10% gains in three sonority groups (Child 13), and one child did not demonstrate gains in any sonority group (Child 11). Children treated with the RW stimuli had more consistent gains, as one child had gains in all seven sonority groups (Child 16) and a second child demonstrated measurable accuracy gains in four sonority groups (Child 15); Child 14 only demonstrated accuracy gains in the lowest cluster sonority group (SD6). It must be noted that Child 13 and Child 15 each had extremely high pre-treatment production accuracy scores for two or three sonority groups, which lessened the

amount of production accuracy change that could be observed; both children were able to essentially maintain their production accuracy scores post-treatment. Thus, when considering the cluster production accuracy scores of the children, both treatment approaches appeared to elicit similar amounts of generalization to untreated clusters.

<Insert figure 4 about here>

DISCUSSION

Using a single-subject multiple baseline design, this study examined the effectiveness of using real words (RWs) and nonwords (NWs) in consonant clusters during the treatment of six children with SSD. In terms of the production accuracy of a consonant cluster targeted in treatment, RWs appeared to be more effective, though children in the NW treatment condition showed larger reductions in the number of sound substitutions produced for their treatment cluster. Concerning system-wide phonological change, NWs appeared to be comparable to RWs in effecting change in untreated consonant singletons and clusters.

Are complex consonant clusters effective speech treatment targets? Regardless of whether the children were in the RW or NW group, some phonological change occurred, be it adding sounds to their phonemic or cluster inventories, reducing their amount of substitution variability, or increasing their overall PCC and/or untreated cluster production accuracy. Because of this it can be said that using complex consonant clusters to treat children with SSD is efficacious.

The findings in this study corresponded well with the findings by Gierut and Champion (2001) in that nearly all of the children increased their production accuracy of their cluster during treatment. However, while Gierut and Champion (2001) did not find any generalization of the cluster targets to untreated words, three of the children in the present study were able to

demonstrate treatment target generalization to untreated words. This difference in results might have been due to the stimulability of the individual consonants in the clusters, the relatively stable phonological systems of the children in the of the present study, and/or the children's slightly older age, all of which could be considered positive predictors of treatment generalization.

In addition, four of the six children added phonemes to their inventories and five of the six children added additional clusters, both two- and three-element. This widespread phonological generalization is consistent with other cluster treatment studies that have found that by targeting one complex consonant cluster, phonological change to less complex clusters and singletons will also occur (Gierut, 1998, 1999; Gierut & Champion, 2001; Powell & Elbert, 1984). Thus, it does appear that by targeting one complex consonant cluster, fairly widespread phonological change can occur in a short period of time.

Do RWs or NWs induce more phonological change in treatment with complex clusters?

Children in the RW group demonstrated greater amounts of accuracy on their cluster during treatment, and had greater generalization accuracy to untreated words containing that cluster. This is consistent with previous studies that manipulated word frequency and found that high frequency words elicited greater phonological changes than low frequency words, or NWs (Gierut et al., 1999; Morrisette & Gierut, 2002).

The one contrary bit of evidence to the effectiveness of RW treatment was the error variability (ECI) analysis. Specifically, NWs induced a larger decrease in the number of incorrect production variants of the treatment targets than did the RWs. This is consistent with previous findings that NWs induced larger decreases in treatment target substitutions (Cummings & Barlow, 2011). Moreover, the fact that treatment with NWs led to greater decreases in

production variability is consistent with Sosa and Stoel-Gammon's (2012) finding that young children produced late-acquired words with greater consistency than early-acquired words. Thus, the fact that the treated NWs were not in the children's lexicons prior to the onset of treatment might have allowed the children to better apply their newly-acquired phonological knowledge of consonant cluster production to their treated words, resulting in more consistent productions.

The error variability analysis also provides a different view of treatment progress that cannot always be captured by simple production accuracy measurements. Error variability measurements might capture initial changes in sound system stability that might need to occur prior to larger system-wide phonological change. Indeed, children with variable error patterns often require more treatment sessions in order to make changes to their sound systems (Dodd & Bradford, 2000; Forrest et al., 2000). To illustrate, the two children (Child 11 & 14) who had the smallest overall PCC gains in treatment both demonstrated ECI score decreases of 33-38%. These data suggest that these children might have been first focusing on making their production of the treatment target more consistent/stable, which could possibly have been followed by later increases in accuracy production had treatment continued. Thus, at a single subject level, this study provides support for the claim that the more varied a child's phonological production of the treatment target is at the outset of treatment, the more likely it is that a delayed, or lack of, response due to treatment will be observed. In other words, changes in ECI scores might be a first step in speech production improvement, with production accuracy changes being observed with additional treatment.

Since both RWs and NWs led to similar amounts of system-wide change in untreated singletons and clusters, their overall treatment effectiveness is comparable. However, depending on the stability of a child's sound system, it is possible that the type of target might affect how

quickly a child can learn to accurately produce a target. In fact, it might be the case that both treatments should be used in combination. Indeed, this is not a new approach to treatment, as it was van Riper who first suggested that nonsense syllables be used in speech treatment to teach children the correct way to produce a given sound in all sound combinations, prior to learning to produce a sound familiar words (van Riper, 1939; van Riper & Erickson, 1995).

To illustrate, NWs could be used to initially stabilize a child's production of a treatment target. Once the child's production variants decrease to ideally just a single (incorrect) production, then RW treatment could begin so that the child could become highly accurate with the treated sound or sound combination. In addition, by using RWs in treatment, the child would be exposed to, and learn, vocabulary that would be useful in communication exchanges with others. Future studies examining the combination of NW and RW treatment approaches could provide more information about this interesting issue.

Another factor to consider when reducing production variation is the number of different words (i.e. exemplars) targeted in treatment. Indeed, it has been observed that the use of just five minimal-pair exemplars is enough for 80% of the children to generalize their treated sound to untreated words (Elbert, Powell, & Swartzlander, 1991). Elbert et al. (1991) suggested that the small number of words facilitated the acquisition of automatic production skills by allowing the children to perfect their phonetic output of just those few exemplars. Thus, the use of five exemplars in present study was perhaps an ideal number of targets, balancing sufficient variability with time-efficiency (of exemplar elicitation). Limiting the number of words allowed the children to learn the correct way to say their treatment words; that is, they not only knew exactly how to produce the target cluster, but also understood how it coordinated with the other sounds in their words.

Treatment limitations and future directions: Language learning considerations. One

limitation of this study was that because of the limited number of words beginning with clusters in the English language, the children might not have known the RW stimuli prior to treatment. To remedy the possibility that some of the RW stimuli could be unfamiliar to children, explicitly teaching the treatment words might improve treatment outcomes. In other words, instead of just presenting the treatment words within the storybook context (in which children were indirectly exposed to the treatment words), a SLP could also take the time to specifically teach a child the meaning and use of each of the treatment words using techniques such as the quick incidental learning approach (QUIL) (Oetting, Rice, & Swank, 1995; Rice, Buhr, & Oetting, 1992). Future studies that first assess children's knowledge of treatment words, and then vary the level of teaching of treatment words could address this issue.

The overall accuracy and/or level of variability in the children's word productions could have potentially been influenced by the treatment words' phonological neighborhood density. Recall that all of the words in the treated study were low in density, primarily due to their consonant cluster construction. However, many previous studies of typically developing and speech disordered children have found that children's successful acquisition of phonology is aided by dense neighborhood structures (Beckman & Edwards, 2000; Edwards, Beckman, & Munson, 2004; Edwards et al., 2004; Gierut & Morrisette, 2014; Pierrehumbert, 2001; Sosa & Stoel-Gammon, 2012; Zamuner, Gerken, & Hammond, 2004). Moreover, one of the oldest forms of speech (articulation) therapy utilizes words from dense neighborhoods (i.e. minimal pairs) to contrast one phoneme with another (Blache, Parsons, & Humphreys, 1981; van Riper, 1939).

To clarify, being presented with words from dense neighborhoods makes children focus on the sound segmental structure and phonemic contrasts in words that might start out as being

stored in a holistic manner; thus, phonologically similar words force children to build finer-grained phonological representations (Gierut & Morrisette, 2014; Stoel-Gammon, 2011; Walley, 1993). Thus, if children had been treated with high-density words containing clusters, greater levels of phonological change could have been observed. While it could be difficult to find RWs that are high in density and still contain clusters, creating high-density NWs with consonant clusters could be a viable treatment option. Future studies comparing high-density and low-density NW cluster words would help tease apart some of the effects of neighborhood density and phonological complexity.

It is also a possibility that children's language abilities might have impacted the treatment outcomes of Child 11 (NW) and Child 14 (RW), as both had severe language impairments (based on the CELF-4 Core Language scores) in conjunction with their speech impairments and both demonstrated limited phonological change. Alternatively, the children with typical language abilities and/or mild language impairments seemed to do equally well in treatment. These results suggest when choosing a speech treatment target, the language abilities of a child should be considered. Children with severe language impairments might not have the overall ability to handle a complex cluster target, especially if it occurs in an unfamiliar word. In other words, children with speech and language disorders possibly have limited information processing capabilities (Hayiou-Thomas, Bishop, & Plunkett, 2004; Ozcebe & Belgin, 2005). Thus, adding any additional cognitive load (e.g. learning the meaning/use of a new word) while learning a complex motor skill (such as speech) may be detrimental to their learning (Maas et al., 2008; Storkel & Morrisette, 2002). It might be more appropriate to either target singleton consonants or less complex cluster targets with children who severe language impairments, at least if unfamiliar RWs or NWs are used in treatment.

Given that this study documented phonological change for children with mild language impairments, but less phonological change for children with severe language impairments, can provide some guidance to SLPs as to what treatment targets might be most beneficial for their clients who may have both speech and language impairments. Future studies involving children with a wider range of language abilities are needed in order to provide more information on the interaction between children's speech and language abilities in treatment.

Treatment limitations and future directions: Complex cluster considerations. The finding that most of the children in both groups could produce their SD2 clusters (i.e. /sm-/ and /sn-/) with higher accuracy than many other clusters is somewhat at odds with the idea of cluster complexity and the Sonority Sequencing Principle (Barlow, 2004; Clements, 1990; Gierut, 1999), in that clusters with smaller SDs should be more complex and harder to acquire and produce than clusters with larger SDs. It may be that the inclusion of early-acquired /m/ and /n/ in the SD2 clusters might make them easier to acquire than less "complex" clusters, such as SD3 clusters, that often contain later-acquired sounds for one or both cluster elements, such as /θɹ-/.

Another interpretation is that not all of the children were treating the /s/ + nasal clusters as true clusters. More specifically, for the children who did not have SD3 clusters, but did produce SD2 clusters (e.g., Child 13, 14, 15, 16), it could be assumed that the SD2 clusters were patterning as adjunct clusters, rather than true clusters, in which case there would not necessarily be an advantage for knowing/producing them (Barlow, 2001, 2004). This is also consistent with Gierut (1999) who found that many children treated the /s/ + stop and /s/ + nasal clusters in a similar manner, leading to the suggestion that any sequence with a sonority distance of two could be interpreted as a natural class. Thus, regardless of whether the sonority rose or fell, the relevant dimension appeared to be the sonority value of two. Future studies involving more children with

a variety of cluster production patterns could provide converging evidence for the possibility that adjunct clusters and the /s/ + nasal clusters should be considered part of the same sonority class.

It would have been ideal if all of the children had not received prior speech services prior to entering into this study, as any gains observed in the children's phonological performance would have been directly attributed to this treatment program. However, all of the children in this sample were relatively older with severe SSDs. Because of this age and severity combination, five of the children had received speech services prior to enrolling in this study. While this is a potential confound, the participants in this study are more comparable to the typical child receiving treatment in the schools. Often children in the schools are in treatment for multiple years and their treatment targets change over time with their phonological learning and development.

The present study attempted to control for prior treatment effects through the use of the multiple baseline design. Namely, the stable pre-treatment baseline measures demonstrated that the children in this study were not able to adequately produce their treatment target prior to the start of treatment, and that the changes in their productions of the target clusters can be directly attributed to the cluster treatment. Interpreting the widespread phonological change (i.e. PCC) can be a bit more complicated because of how prior treatment might have "readied" the children's phonological systems for change. However, the children's overall PCC changes were consistent with prior studies that required children to not have prior speech treatment upon their enrollment in a research program (Allen, 2013; Almost & Rosenbaum, 1998; Gierut & Morrisette, 2014; Tyler et al., 2003; Tyler, Williams, & Lewis, 2006), suggesting that the prior treatment effects on this study's outcomes might have been minimal. Moreover, the 3-13%

increases in PCC were consistent with ideas of significant generalization per the assumptions of single-subject designs (e.g. McReynolds & Kearns, 1983).

The prior treatment targets, and subsequent phonological knowledge that the children gained from previous treatment are also important when considering targeting clusters in speech treatment, and especially when considering three-element clusters. Specifically, Gierut and Champion (2001) found that when the first (C1) and second (C2) consonants of a three-element cluster were in a child's phonemic inventory, generalization was minimal after treatment with a 3-element cluster – presumably because the child emphasized the first two sounds of the sequence, essentially highlighting the adjunct portion of the cluster. Alternatively, Gierut and Champion (2001) found that when the second (C2) and third (C3) consonants of the three-element cluster were phonemic, generalization was expansive after treatment – presumably because the child emphasized the second and third sounds in the cluster, which was the true portion of the cluster. Thus, Gierut and Champion (2001) claimed that depending on what sounds are in the child's phonemic inventory, the child could potentially have different levels of learning and generalization after treatment with a three-element cluster.

In the present study, all five children who had received prior speech treatment had worked on a part of their targeted cluster in previous treatment programs – specifically, either the singleton /ɹ/ or the /st/ cluster was targeted previously. Three of the four children treated with /stɹ/ did not have /ɹ/ in their phonemic inventories (Child 12, 14, & 15); however, all three were stimulable for /ɹ/ and it was in their phonetic inventories – meaning that they produced it in at least two separate word contexts. Thus, while /ɹ/ was not produced contrastively in two separate minimal pairs, as is required to be considered part of the phonemic inventory, all children had the ability

to produce the sound. Thus, it was decided that this phonetic level of knowledge was potentially enough to allow the children to be successful in cluster treatment.

Given that Child 12 and 15 successfully produced their target cluster in at least 2 separate occurrences post-treatment, and the fact that Child 15 also added /ɪ/ to his phonemic inventory, it would appear that for many children phonetic knowledge and/or stimulability of C3 could be enough to ensure three-element cluster generalization. Alternatively, given that Child 14 did not add any clusters or /ɪ/ to her inventories post-treatment, having typically developing language skills might be an additional requirement if phonemic status of C3 is not established prior to beginning treatment.

It is important to note is that while many of the children in this study did not have all of their cluster consonants (especially C2 and C3) in their phonemic inventories, they still demonstrated widespread change/improvement to their sound system, both in terms of their target cluster production, as well as to untreated singletons and clusters. This is somewhat counter to the claims of Gierut and Champion (2001) that it might not be appropriate to target clusters containing sounds not present in the phonemic inventory. This is definitely a direction for further study: It may be necessary to redefine what phonological characteristics should be present prior to beginning speech treatment with complex clusters. At the very least, the present study suggests that cluster treatment target selection should not necessarily be so constrained by children's phonemic knowledge.

Conclusion

This treatment study compared the efficacy of RW and NW targets containing word-initial complex clusters in the treatment of children with SSD. The RW treatment led to more accurate productions of a treatment target, while NW treatment resulted in a greater decrease in error

variants for the treated cluster. Both types of treatment resulted in similar amounts of system-wide phonological change, even though not all of the cluster segments were present in many of the children's phonemic inventories. Thus, the procedures previously suggested for cluster target selection may need to be re-addressed. In summary, both RWs and NWs containing complex clusters should be considered to be efficient and efficacious options when working with children who have SSD. However, given the functionality and usefulness of RWs and NWs ability to stabilize children's sound systems, it is possible that a combination the two might prove to be the most effective treatment approach.

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Declaration of Interest.

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Figure Captions

Figure 1. Sonority distance (SD) of all true English clusters. Clusters with SD of 6 are considered to be less complex than clusters with SD of 2. The /s/ + stop “adjunct” clusters (sp-, st-, and sk-) violate the Sonority Sequencing Principle, resulting in a SD of -2. Note: “V” corresponds to voiced consonants, while “VL” corresponds to voiceless consonants.

Figure 2. Children’s percentage production accuracy of the treated clusters in non-words (NWs) and real words (RWs) during baseline, treatment sessions, and at the two-week post-treatment MCOP session. All children completed 2 to 3 baseline sessions and 12 treatment sessions. Three distinct learning patterns were observed: 1) no change from baseline levels (Child 14), 2) sporadic learning (Child 11), and 3) consistent learning (Children 12, 13, 15, & 16). In all figures, the data for the children in the NW condition (11-13) are presented on the left side of the figure and the RW condition (14-16) are on the right.

Figure 3. Pre-treatment and two-week post-treatment percent consonants correct (PCC) measurements, as well as the PCC change from pre- to post-treatment, as measured by the AEP probe. Four of the children achieved at least a 10% PCC increase from pre-treatment baseline levels (Children 12, 13, 15, & 16).

Figure 4. Untreated cluster percentage of accuracy production for pre- and post-treatment, as well as the percentage of change observed. Cluster sonority groups were considered to have generalization if a 10% or greater accuracy gain was observed. Four of the children demonstrated accuracy gains across at least three different cluster sonority groups (Children 12, 13, 15, & 16).

Table 1. Participant characteristics of the three children in the real word (RW) and nonword (NW) treatment conditions.

	Nonword (NW) Treatment			Real Word (RW) Treatment		
	Child 11	Child 12	Child 13	Child 14	Child 15	Child 16
Gender	Male	Male	Male	Female	Male	Male
Age at start of Treatment	5;7	5;10	6;2	5;3	5;8	5;4
Months of Prior Treatment Services	18 months	9 months	12 months	15 months	9 months	0 months
Prior RW Treatment Targets	/ɪ/, /ə/	/k/, /g/, /sp/, /st/, /sk/	/l/, /ɪ/	/tʃ/, /l/	/k/, /g/, /sp/, /st/, /sk/	N/A
Prior NW Treatment Targets	/tʃ/, /l/	N/A	N/A	/ɪ/	N/A	N/A
Treatment Cluster	/stɪ/	/stɪ/	/əɪ/	/stɪ/	/stɪ/	/əɪ/
Pre-Treatment Cluster Sound Stimulability	/s/, /t/, /ɪ/	/s/, /t/, /ɪ/	/ə/, /ɪ/	/s/, /t/, /ɪ/	/s/, /t/, /ɪ/	/ɪ/
GFTA-2 Raw Score (# of errors)	40	27	23	32	32	35
GFTA-2 Standard Score	56	70	74	71	66	66
PPVT-4 Standard Score	93	89	118	88	89	94
Leiter-R Standard Score	105	97	113	109	103	95
CELF-4: Core Language Index Standard Score	44	85	101	69	72	97
Hearing Screening	Pass	Pass	Pass	Pass	Pass	Pass

- The *Goldman Fristoe Test of Articulation -2* (GFTA-2; Goldman & Fristoe, 2000), *Peabody Picture Vocabulary Test – IV* (PPVT-4; Dunn & Dunn, 1997), *Clinical Evaluation of Language Fundamentals – 4th ed.* (CELF-4; Semel, Wiig, & Secord, 2003), and *Leiter International Performance Scale – Revised* (Leiter-R; Levine, 1997) yield standard scores with M=100 and SD=15.
- The CELF-4 Core Language Index assesses semantics, morphology, syntax, and sentence memory.

Table 2. Listing of the phonemes missing from each child's pre-treatment phonemic inventory (i.e., two separate occurrences), as well as the phonemes that were added to the child's phonemic inventory post-treatment.

Child	Treated Cluster	Treatment Condition	Sounds Missing from Phonemic Inventory Pre-Treatment ^a	Sounds Added to Phonemic Inventory Post-Treatment ^a	Phonemes Added	Percent Phonemes Added
Child 11	/stɪ/	NW	ə ð ʃ	ʃ	1	33
Child 12	/stɪ/	NW	v ə ð s z ʃ tʃ ɔ̃ l ɪ	s ʃ tʃ ɔ̃	4	40
Child 13	/əɪ/	NW	ə ɪ	NA	0	0
Child 14	/stɪ/	RW	g ə z ɪ	ə	1	25
Child 15	/stɪ/	RW	ə ð z ʃ tʃ ɪ	ð tʃ ɪ	3	43
Child 16	/əɪ/	RW	ə ð	NA	0	0
^a Pre-Treatment inventories calculated from pre-treatment and baseline sessions						
^b Post-Treatment inventories calculated from 2-week post sessions						

Table 3. Listing of the clusters present in the pre-treatment phonetic inventory of the children in the nonword (NW) treatment condition, organized by sonority distance (SD). Clusters that were added to the children's post-treatment phonetic inventories are listed as well. Each child's pre-treatment minimum sonority distance is listed. See text for more details.

	Clusters Present in Phonetic Inventory Pre-Treatment By Sonority Distance ^a							Clusters Added to Phonetic Inventory Post-Treatment By Sonority Distance ^b							Pre-Treatment Minimum Sonority Distance	Number of Clusters Added Post-Treatment
	SD6	SD5	SD4	SD3	SD2	SD-2	3-element	SD6	SD5	SD4	SD3	SD2	SD-2	3-element		
Child 11	kw	bw dw gw	bl gl gr					kl	br				st		4	3
Child 12	pw tw	pl pr tr kr gw	br dr gr fr	fr fl fl fw				kw	kl	bl gl sw		sm sn	sp st sk	spl skr skw	3	13
Child 13	pw tw kw	bw gw	sw fw ew fw		sm sn	sp st		kl	br gl				sk	skw	2	5

^aPre-Treatment inventories calculated from pre-treatment and baseline sessions

^bPost-Treatment inventories calculated from 2-week post sessions

Table 4. Listing of the clusters present in the pre-treatment phonetic inventory of the children in the real word (RW) treatment condition, organized by sonority distance (SD). Clusters that were added to the children's post-treatment phonetic inventories are listed as well. Each child's pre-treatment minimum sonority distance is listed. See text for more details.

	Clusters Present in Phonetic Inventory Pre-Treatment By Sonority Distance ^a							Clusters Added to Phonetic Inventory Post-Treatment By Sonority Distance ^b							Pre-Treatment Minimum Sonority Distance	Number of Clusters Added Post-Treatment
	SD6	SD5	SD4	SD3	SD2	SD-2	3-element	SD6	SD5	SD4	SD3	SD2	SD-2	3-element		
Child 14	pw tw kw	ti bw dw gw	di sw fw		sm sn										2	0
Child 15	pw tw kw	pl pi ti kl ki bw dw gw	bl gl sw fw	fi	sm sn	sp st sk	spl ski spw stw skw			bi di gi	fl sl fi			sti	2	7
Child 16			fw		sm sn	st			pi ti	bi di gi	fl fi ei fi		sk	spi	2	11

^aPre-Treatment inventories calculated from pre-treatment and baseline sessions

^bPost-Treatment inventories calculated from 2-week post sessions

Table 5. Word density, word frequency, phonotactic probability, and age of acquisition (AoA) measurements for the real word (RW) and nonword (NW) cluster stimuli used in the study. The density and frequency measurements were calculated using the Washington University in St. Louis Speech and Hearing Lab Neighborhood Database on-line calculator at: <http://128.252.27.56/Neighborhood/Home.asp>. Real words not appearing in the database were assumed to be low in frequency (i.e., less than 100 words/million). Words with fewer than 10 phonological neighbors were assumed to be low in density. Phonotactic probability measurements (i.e., phoneme and biphone probabilities) were calculated using the on-line Phonotactic Probability Calculator at: <http://www.people.ku.edu/~mvitev/PhonoProbHome.html>. AoA measurements were calculated using the Kuperman et al. (2012) AoA norms found at: <http://crr.ugent.be/archives/806>.

NW	NW Density*	NW Phoneme Probability	NW Biphone Probability	RW Match	RW Density	RW Phoneme Probability	RW Biphone Probability	RW Frequency	RW AoA (years)
stʁʌndʒ	2	0.3051	0.0269	strange	0	0.3082	0.0290	84	6.42
stʁiɛŋ	7	0.2348	0.0258	strong	2	0.2246	0.0251	202	4.58
stɹʌps	6	0.2942	0.0256	stripes	3	0.2953	0.0256	4	4.05
stɹɪbʊɹæz	0	0.3510	0.0327	strawberries	0	0.3767	0.0447	N/A	4.21
stɹi	7	0.2513	0.0306	straw	2	0.2124	0.0245	15	4.22
θɹiɪd	4	0.1527	0.0081	thrill	4	0.1686	0.0172	5	8.37
θɹoʊg	4	0.1303	0.0087	threat	3	0.2130	0.0102	42	7.14
θɹɔɪ	3	0.0993	0.0021	threw	8	0.1128	0.0057	1015	5.82
θɹɔ	5	0.1028	0.0036	three	8	0.1169	0.0098	610	3.69
θɹɔɪʔəd	0	0.1364	0.0022	throughout	0	0.1947	0.0068	141	15.85
Average Values	3.8	0.2058	0.0166	Average Values	3.0	0.2223	0.0190	211.8	6.44

* NW Density represents the number of real words that differ from the non-word by one phoneme. Specifically, the phonological form of the NW was inputted with the neighborhood criteria accounting for substitutions, deletions, and additions.

Table 6. The Error Consistency Index (ECI) calculated for each child in the study. The ECI was determined by observing how many different sound combinations each child produced for his/her treated cluster both pre-treatment and at the two-week post-treatment probe session. The ECI value included full and partial omissions of the cluster (e.g., "street" /stɹi:t/ produced as "seat" [sit] or "steet" [stit]), as well as correct productions of the treated cluster.

Subject	Cluster	Condition	Error Consistency Index ^A		
			Pre-Tx Treatment Cluster ^B	Post-Tx Treatment Cluster ^B	Treatment Sound Proportion Change (Negative Values)
Child 11	/stɹɪ/	NW	8.00	5.00	0.38
Child 12	/stɹɪ/	NW	5.00	3.00	0.40
Child 13	/θɹɪ/	NW	2.00	1.00	0.50
		Average	5.00	3.00	0.43
Child 14	/stɹɪ/	RW	3.00	2.00	0.33
Child 15	/stɹɪ/	RW	5.00	2.00	0.60
Child 16	/θɹɪ/	RW	4.00	4.00	0.00
		Average	4.00	2.67	0.31

^AThe Error Consistency Index does include the correct cluster productions, if produced by each child. The ideal Error Consistency Index number is 1.0, meaning that only one cluster exemplar was produced for each cluster.

^BWhen a cluster is targeted in treatment, the Error Consistency Index refers to the number of substitutions for the entire cluster.

SD = 6	SD = 5	SD = 4	SD = 3	SD = 2
VL Stop + Glide	VL Stop + Liquid	V Stop + Liquid VL Fricative + Glide	VL Fricative + Liquid	VL Fricative + Nasal
tw	pl	bl	fl	sm
kw	pr	bɹ	fɹ	sn
	tɹ	dɹ	θɹ	
	kl	gl	sl	
	kɹ	gɹ		
		sw		
<i>Least Sonorous</i>				<i>Most Sonorous</i>

Daily production accuracy of treatment target

Cluster Production Percentage Accuracy, by sonority distance

Appendix 1. The 256 word and picture stimuli elicited by the computerized Assessment of English Phonology (Barlow, 2003) phonological probe.

glasses	ladder	yawn	web i	run	stir ing
ghost	magic(ian)	prince(ss)	hill	run ing	rake
six	rabbit	smoke	hill i	hug	rake ing
vacuum	other	thermometer	train	hug ing	read
elephant	rocket	mop	train i	smile	read ing
zebra	space	chain	mud	smile ing	drive
zoo	ocean	soap	mud i	splash	drive ing
brush	teacher	soap i	page	splash ing	throw
blue	finger	fish	page i	blow	throw ing
plate	wagon	fish i	dog	blow ing	snow
knife	chair	bath	dog i	skate	snow ing
shark	thirsty	bath i	bed	skate ing	
teeth	queen	tub	bed i	break	
feather	twins	tub i	cheese	break ing	
green	them	thumb	cheese i	swing	
vanilla	zipper	thumb i	square	swing ing	
shovel	pig	frog	square i	buzz	
this/that	screw	frog i	comb	buzz ing	
there	shower	car	comb i	catch	
yoyo	theirs	car i	ice	catch ing	
guitar	thunder	leaf	ice i	kiss	
lemon	vest	leaf i	peach	kiss ing	
yellow	treehouse	glove	peach i	ride	
stretch	cob	glove i	duck	ride ing	
popcorn	these/them	chalk	duck i	rub	
mother	sun	chalk i	ring	rub ing	
father	pie	juice	ring i	shave	
behind	drum	juice i	watch	shave ing	
yes	water	cup	watch i	cough	
you	toes	cup i	door	cough ing	
present	twelve	witch	door i	crash	
thank you	zero	witch i	bridge	crash ing	
please	gum	hat	bridge i	swim	
strawberry	three	hat i	mouth	swim ing	
snail	judge	badge	mouth i	fall	
beehive	jelly	badge i	wish	fall ing	
chicken	brother	nose	wish i	sing	
cloud	(french) fries	nose i	stove	sing ing	
flower	skunk	off	stove i	sleep	
vase	noise	off i	cage	sleep ing	
music	quiet	moth	cage i	dig	
sock	shoes	moth i	spring	dig ing	
jeep	zipping	robe	spring i	rain	
doll	crayons	robe i	goat	rain ing	
game	grapes	tooth	goat i	hiss	
nail	slippers	tooth i	laugh	hiss ing	
hammer	jump(rop)ing	van	laugh ing	climb	
hanger	light (lamp)	van i	fly	climb ing	
nothing	spoon	web	fly ing	stir	

Appendix 2. Probe of Onset Clusters, adapted from Gierut (1998).

pɪ	pretzel princess pretty prize present	fɪ	fruit frog french fries friend front	sm	smell smile small smoke smooth	skɪ	scream scratch scrub scribble screw
bɪ	bread brush broom bridge brown	θɪ	three throw thread throne throat	sn	sneeze snowman snake snail snack	skw	squeak square squirrel squeeze squirt
tɪ	tree truck train trick-or-treat triangle	ʃɪ	shrink shrub shrug shrimp shred	sw	swing swim sweep sweater sweet	tw	twinkle tweety twelve twins twist
dɪ	dress drum drive draw drink	pl	plate plane plant play plug	spɪ	sprite spring spray sprinkler	kw	quack queen quarter quiet quilt
kɪ	crayon cry crawl crack cream	bl	black blocks blow blanket blue	spl	splash splinter split splitting	Cj	music viewmaster cute few beauty
gɪ	grass green grow grapes grandma	kl	clown clean clock clothes cloud	stɪ	stranded street straight string strap		

Appendix 3. Example story used to present words for /stɹ/ treatment

How the zebras got their *stups/stripes*

Today we're on the trail of a *stundz/strange* mystery: How did the Zebras get their *stups/stripes*? We're here at the local watering hole on the plains of Africa with some talkative creatures that say they know the answer to this *stundz/strange* mystery of the Zebra's stripes. "Long ago," said Giraffe, "there were two kinds of zebras – the all-white kind and the all-black kind. The all-black kind was this color because all they ate was *stɹi/straw*. Everyone knows that if you only eat *stɹi/straw* you will have black fur. The black zebras were also so hot in the African sun." "Yes," said Ostrich, "and the white zebras only ate *stɹɪburæz/strawberries*! Everyone knows that if you only eat that fruit you will have white fur. The white zebras weren't hot from the sun, but *stɹem/strong* lions could always find them."

"One day," said Giraffe, "the zebras went to Baboon for help. He gave the black zebras *stɹɪburæz/strawberries*. And he gave the white zebras *stɹi/straw*. The zebras had a hard time switching their food, because they found the other food to be *stundz/strange*. After a few days of the white zebras only eating *stɹi/straw* and the black zebras only eating *stɹɪburæz/strawberries*, a very *stundz/strange* thing happened. The zebras switched colors completely! Now the white zebras were black and the black zebras were white."

"They really thought their problems were solved," exclaimed Ostrich, "but they were still having the same problems with the sun and the *stɹem/strong* lions. So, they went back to the Baboon for help." Those poor zebras begged the baboon for help, "Please help us Baboon, we are still so scared of the sun and the *stɹem/strong* lions," said the Zebras.

"I have the answer to your *stundz/strange* problem," Baboon said, "You have to eat a mix of the *stɹɪburæz/strawberries* and *stɹi/straw*. If you eat both of these foods you will have both white and black fur. This should solve your problem!" So, the zebras followed the advice and soon they had black and white *stups/stripes*. They were suddenly *stupt/striped* creatures that could outsmart the African sun and *stɹem/strong* lions.

The zebras soon realized that their *stups/stripes* were a great way to escape the *stɹem/strong* lions and the African sun. Even though the other animals laughed at their *stups/stripes*, they kept eating *stɹɪburæz/strawberries* and *stɹi/straw* to keep safe. Now, they are proud of their *stups/stripes*, because even though they are *stundz/strange*, they keeps them *stɹem/strong* and healthy.