Phonological Priming in Young Children Who Stutter: Holistic Versus Incremental Processing

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Purpose: To investigate the holistic versus incremental phonological encoding processes of young children who stutter (CWS; $N = 26$) and age- and gender-matched children who do not stutter (CWNS; $N = 26$) via a picture-naming auditory priming paradigm.
Method: Children named pictures during 3 auditory priming conditions: neutral, holistic, and incremental. Speech reaction time (SRT) was measured from the onset of picture presentation to the onset of participant response.
Results: CWNS shifted from being significantly faster in the holistic priming condition to being significantly faster in the incremental priming condition from 3 to 5 years of age. In contrast, the majority of 3- and 5-year-old CWS continued to exhibit faster SRT in the holistic than the incremental condition.
Conclusion: CWS are delayed in making the developmental shift in phonological encoding from holistic to incremental processing, a delay that may contribute to their difficulties establishing fluent speech.

Key Words: children, stuttering, phonology, holistic, incremental

Although the cause of stuttering still remains unknown, developing lines of evidence appear to suggest that phonology may contribute to childhood stuttering. Findings from descriptive studies indicate that articulatory/phonological difficulties are common among children who stutter (CWS; e.g., Blood, Ridenour, Qualls, & Hammer, 2003; for reviews, see Bloodstein, 1995, Table 18; Louko, Edwards, & Conture, 1990; cf. Nippold, 1990, 2002). However, at present, there is no completely satisfactory theoretical account for the nature of this co-occurrence. To address this concern, we have shifted our focus from a descriptive study of the relationship between phonology and stuttering to an experimental investigation of this relationship. Such experimental exploration allows for control over selected aspects of phonology and, thus, a better idea of how phonology might contribute to the onset, development, and/or maintenance of childhood stuttering. Specifically, through experimental manipulation of the process of phonological encoding, the rapid mapping of the syntactic/meaning aspects of a word (i.e., lemma) onto the phonological form of a word (i.e., lexeme; Levelt, 1989), we suggest that a more objective understanding of the relationship between phonology and stuttering in young children can be obtained.

Consistent with our suggestion, Hakim and Bernstein Ratner (2004) recently reported a study of the phonological encoding of CWS age 4;3–8;4 (years; months; $M = 5;10$) and age- and gender-matched children who do not stutter (CWNS). These researchers employed a nonword repetition task that included 40 nonsense words consisting of 10 words composed of two syllables, 10 of three syllables, 10 of four syllables, and 10 of five syllables. The series of 10 words composed of four syllables were repeated a second time but with an altered stress pattern that was atypical of English. Results indicated that CWS performed more poorly than their CWNS peers relative to number of words correct and number of phoneme errors at all nonword lengths, but only significantly so for the repetition of the three-syllable nonwords. Hakim and Bernstein Ratner (2004) took these findings to suggest that CWS may have a deficiency in their ability to hold novel phonological sequences in memory and, subsequently, in their ability to adequately reproduce those novel sequences. Perhaps, this deficiency affects the speed with which CWS are able to phonologically encode words.

To investigate such a possibility, Melnick, Conture, and Ohde (2003) phonologically primed the picture naming of 18 CWS (mean age = 50.67 months) and 18 age- and gender-matched CWNS (mean age = 49.44 months). For this task, immediately prior to picture presentation, participants were either (a) not presented with an auditory prime (i.e., no prime condition), (b) presented auditorily with a related prime that was composed of the consonant onset plus the formant transitions and most of the vowel of the name of the target picture (i.e., related prime condition), or (c) presented auditorily with an unrelated prime that was composed of a consonant onset plus formant transitions and most of the vowel target of a word that did not correspond with the target picture (i.e., unrelated prime condition). Results indicated no significant difference between CWS and CWNS in their facilitation to the phonologically related prime, with both talker groups demonstrating faster speech reaction times (SRTs) when presented with a related prime than with a no prime or an unrelated prime. However, Melnick et al. did find a developmental facilitation effect for the related prime condition between 3- versus 5-year-old CWNS but not between 3- versus 5-year-old CWS. Specifically, 5-year-old CWNS, when compared with 3-year-old CWNS, demonstrated a faster SRT for the related prime condition, but no such age-related differences in SRT were noted for CWS. This finding may indicate that CWS continue to use a more immature form of phonological encoding (i.e., holistic processing) at a later age in development than is typically expected.

Holistic processing has been defined as processing at the syllable or global unit of speech (see Charles-Luce & Luce, 1990; Walley, 1988). By comparison, incremental processing has been defined as the processing of the word as individual sounds from the beginning to the end of the word (i.e., left to right). Although extant data indicate that infants are able to discriminate between individual sound segments (Jusczyk, Bertoncini, Bijelic-Babic, Kennedy, & Miller, 1990; Kemler Nelson, Jusczyk, Mandel, Myers, & Turk, 1995), it should be noted that those particular findings pertain to sound groups *without meaning* rather than speech-language production involving *meaning*. For the purposes of the present study, as will be discussed below, we focused on the holistic to incremental processing shift thought to occur when young children begin to attach *meaning* to sound groups, that is, when they begin to develop a vocabulary.

Several researchers have empirically studied holistic/incremental processing in children. For example, it has been shown that typically developing young children's phonological representations are considered to be more holistic than older children and adults (Walley, 1988, 1993; Walley, Smith, & Jusczyk, 1986). This difference, it has been speculated, may be due to young children's tendency to "employ more global recognition strategies because words are more discriminable in memory" (Charles-Luce & Luce, 1990, p. 205). Likewise, Walley (1988) contends that the expansion of the child's mental lexicon requires addition of more detailed, discriminating phonological information to the child's phonological representations of lexical concepts. This "expansion" appears to allow the child to differentiate more efficiently among phonologically similar representations (Aslin & Smith, 1988; Walley, 1988).

More recently, Brooks and MacWhinney (2000) employed a priming paradigm to investigate the notion of holistic versus incremental encoding in typically developing children and adults. Similar to Melnick et al. (2003), they reported that older children and adults exhibited faster SRTs with phonologically related auditory onset (i.e., incremental) primes than with "rhyme" primes or primes containing the same nucleus and coda of the original word but a different initial sound (i.e., holistic primes). Conversely, younger children exhibited faster SRTs when presented with rhyme primes than with onset primes. Brooks and MacWhinney took these findings to suggest that the onset of the word has an increased importance with development, lending support to an incrementalist view of speech production. These investigators further speculated that young children may intend or try to use a mature language form that requires incremental processing but do not yet have the ability to functionally encode in a more finely discriminative pattern than the syllable. In other words, these children may be trying to produce utterances that require a more incremental level of processing but are still functioning at a holistic encoding stage of processing. Brooks and MacWhinney conjectured this confluence of more mature intention and less mature abilities might account for why young children as a group are more disfluent than adults. Perhaps the phonological encoding of young CWS may be less mature than their CWNS peers because of difficulties young CWS have making the developmental shift from holistic to incremental processing.

Proponents of the holistic to incremental processing shift contend that young children experience a vocabulary spurt at around 18 months of age. The occurrence of this spurt is an ongoing phenomenon that is thought to ultimately force the child to shift to a more incremental form of processing (Charles-Luce & Luce, 1990; Walley, 1988). Thus, this time frame between the onset of the vocabulary spurt and the noted increase in speech disfluencies in all children may reflect a temporary mismatch between processing strategy and processing needs. If that is the case, then those children who are able to make the shift from holistic to incremental processing within the expected developmental time frame will be those children whose noted increase in speech disfluencies will considerably decline. By comparison, if, despite this vocabulary spurt, a child continues to rely on holistic processing, then this persistent use of a less than efficient means for dealing with an ever increasing corpus of phonological representations of lexical concepts may contribute to the 30- to 36-month mean time of onset of developmental stuttering (e.g., Mansson, 2000; Yairi & Ambrose, 1999; Yaruss, LaSalle, & Conture, 1998). Although the putative shift from holistic to incremental processing is but one of several changes that may occur with 30- to 36-month-old children, it seems reasonable to suggest that childhood stuttering may be more likely to begin during the developmental period when changes from holistic to incremental processing are most apt to occur and/or begin in typically developing children (i.e., CWNS).

Therefore, the purpose of the present study was to assess the holistic versus incremental phonological encoding processes of young CWS and CWNS through the use of a picture-naming priming paradigm. This paradigm allows for experimental manipulation of the time course or speed of the covert linguistic planning processes that lead to participants' overt speech-language production. Based on previous research (Melnick et al., 2003; Zackheim, Conture,

& Ohde, 2002), it was hypothesized that both CWS and CWNS at 3 years of age would exhibit faster SRTs when presented with a holistic prime than an incremental prime. However, by age 5, the CWNS would be faster when presented with an incremental prime than holistic prime, whereas the CWS would continue to be faster when presented with the holistic prime than an incremental prime. Such findings would lend support to our theory that a delay in development of incremental processing may contribute to the difficulties CWS have establishing normally fluent speech-language production.

Method

Participants

Participants were 52 monolingual children who spoke Standard American English, including 3-year-old (mean age = 38.3 months, $N = 13$) and 5-year-old (mean age = 62.5 months, $N = 13$) CWS that were matched for age (±3 months) and gender with the same number of CWNS. Participants were paid volunteers who were naive to the purposes and methods of the study. CWS were referred to the Vanderbilt Bill Wilkerson Center by their parents, speech-language pathologists, or day care, preschool, or school personnel. CWNS were recruited by word of mouth or through a newspaper advertisement. Participants had no known or reported hearing, neurological, developmental, academic, intellectual, or emotional disorders. The study protocol was approved by the institutional review board at Vanderbilt University in Nashville, TN. Informed consent was obtained for each of the 52 participants.

Classification and Inclusion Criteria

Speech Disfluency

Research (Wolk, 1990) has indicated that speech disfluencies for CWS are significantly greater during conversation than during picture-naming or picture description tasks; therefore, measures of speech disfluency were based on the children's conversational speech during a parent–child interaction. For each parent–child interaction, the general principles of natural conversation were adhered to (see Zackheim & Conture, 2003, for review of protocol).

CWS. A child was considered as stuttering if he or she exhibited *3 or more* stuttering moments (i.e., sound/syllable repetitions, sound prolongations, broken words, and/or monosyllabic whole-word repetitions) per 100 syllables of conversational speech (Bloodstein, 1995; Conture, 1990, 2001; Pellowski & Conture, 2002) and a total overall score of 11 or above (i.e., a severity equivalent of at least "mild") on the Stuttering Severity Instrument for Children and Adults, Third Edition (SSI–3; Riley, 1994). It is important to note that although these classification criteria for stuttering are not universally accepted (see Wingate, 2001), they are based on extensive research (Ambrose & Yairi, 1999) that has been replicated by one of the present authors (Pellowski & Conture, 2002).

CWNS. A child was considered as not stuttering if he or she exhibited *2 or fewer* stuttering moments per 100 syllables of conversational speech (Conture & Kelly, 1991; typically 90% or more of CWNS exhibit less than 3% stuttering; see Conture, 2001, Table 1.2) and a total overall score of 8 or below (i.e., a severity equivalent of less than mild) on the SSI–3 (Riley, 1994).

Hearing, Speech, and Language Abilities

Prior to experimental testing, participants passed pure-tone and tympanometric screening (American Speech-Language-Hearing Association, 1990) and were administered the Peabody Picture Vocabulary Test—III (PPVT–III; Dunn & Dunn, 1997); Expressive Vocabulary Test (EVT; Williams, 1997); Test of Early Language Development, Third Edition (TELD–3; Hresko, Reid, & Hamill, 1991); and Goldman Fristoe Test of Articulation (GFTA; Goldman & Fristoe, 1986) to assess receptive and expressive vocabulary, receptive and expressive language skills, and articulation abilities, respectively. On average, participants scored above the 60th percentile rank for their chronological age group (see Table 1).

Race

Each child's race was based on parental verbal identification of child/parent race. Participants were not matched for race, but an effort was made to achieve a comparable racial/ethnic distribution. Specifically, among the 3-year-old CWNS, 12 were White, and 1 was Black. For the 5-year-old CWNS, 10 were White, 2 were Black, and 1 was Asian American. Within the 3-year-old CWS, 10 were White, and 3 were Black; for the 5-year-old CWS, 10 were White, and 3 were Black.

Socioeconomic Status

Socioeconomic status (SES) was calculated for the parents of all participants through application of parent occupation to the Two-Factor Index of Social Position (as cited in Myers & Bean, 1968), a modification of the Alba Edwards system of classifying occupations into SES groups based on the U.S. Bureau of the Census. There were no significant differences in SES between CWS and CWNS, $F(1, 50) = 0.305$, $p = .583$.

Collection of Data for Phonological Priming

General Procedures/Instrumentation

Approximately 1 to 2 weeks after testing in each participant's home, the participant completed experimental testing in the laboratory. The participant was instructed to sit in front of a Pentium 200-MHz computer with 20-in. Sony Trinitron monitor and told to name pictures displayed on the screen. Presentation of target pictures and auditory primes as well as collection and analysis of SRT were performed

TABLE 1. Mean percentile rank and standard deviation for children who stutter (CWS) and children who do not stutter (CWNS) for the following standardized speech-language tests: Goldman Fristoe Test of Articulation (GFTA); Peabody Picture Vocabulary Test—III (PPVT–III); Expressive Vocabulary Test (EVT); and Test of Early Language Development, Third Edition (TELD–3).

	CWS		CWNS	
	M	*SD*	*M*	*SD*
GFTA	73	22	75	21
PPVT–III	67	24	79	19
EVT	73	23	84	16
TELD–3 receptive subtest	65	27	87	12
TELD–3 expressive subtest	74	24	81	15

using the New Experimental Stimulus Unit software and coprocessor, a data collection and analysis system designed to measure chronometric data, developed by the Max Planck Institute in Nijmegen, The Netherlands.

Picture Stimuli

Each participant was presented with the same set of 12 pictures in each condition (see Table 2). Preliminary investigation (Zackheim et al., 2002) indicated that these 12 pictures were associated with an overall mean percentage correct naming score of 98% for 3- to 5-year-old typically developing children ($N = 43$). This percentage correct naming score took into account not only whether the participant said the target word but also whether she or he said it fluently and articulated it correctly, thereby ensuring the use of pictures that would yield fluent, correctly articulated, and accurately named responses.

Stimulus (Prime) Generation

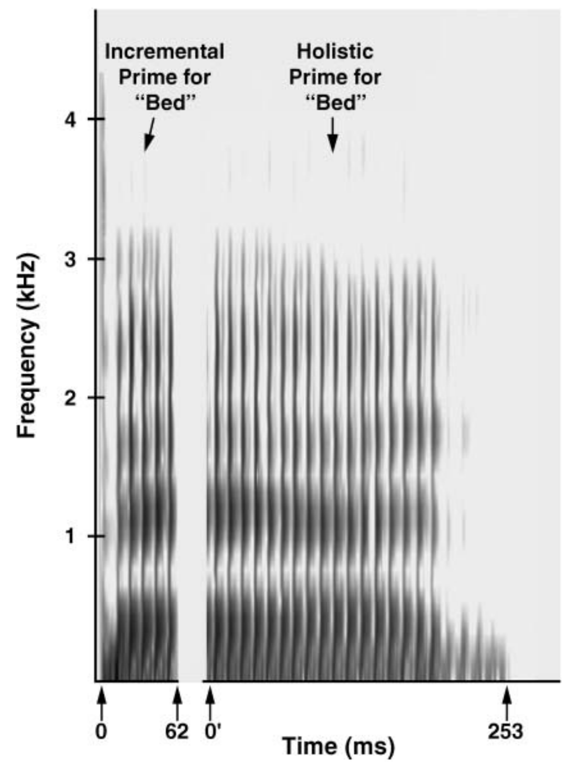
One adult male recorded the primes for the present study. He was a native monolingual English speaker with a Midland dialect (Labov, 1991) who had no history of a speech, language, or hearing disorder. Acoustic recordings of the auditory primes were performed in a sound-attenuated booth with a Shure Prologue 14H Hi Z Dynamic omnidirectional microphone placed approximately 12 in. from the speaker's mouth. The recordings of the words were converted into digital form using the Kay Elemetrics Computerized Speech Lab (CSL; Version 5.0) at a 22050-kHz sampling rate and 16-bit quantization. An acoustic segmentation function in CSL was used to produce the holistic and incremental primes. All segmentations were made at zero crossings. The first and third author listened to all the stimuli, and none contained audible clicks or background noise. Figure 1 provides a spectrographic illustration of the incremental and holistic primes for the target word *bed*. In support of our perceptual observations, the spectrogram reveals no inappropriate clicks or noise artifacts.

TABLE 2. The duration (in milliseconds) of the twelve target words (picture) for the holistic primes, and the duration (in milliseconds) and number of glottal pulses from the formant transition for the incremental primes used in the picture-naming priming experiment.

No.	Picture	Holistic	Incremental	No. of glottal pulses
1	ball	339	89	6
2	dog	280	74	6
3	snake	230	198	5
4	house	353	97	5
5	scissors	456	170	2
6	plane	278	126	5
7	book	186	45	2
8	fish	316	110	4
9	bed	253	62	5
10	candle	341	100	6
11	horse	371	85	2
12	whistle	270	103	3
M		306	105	4
SD		72	43	2

Note. The duration of the incremental primes is the sum of the duration of the initial consonant plus the duration of the glottal pulses of the formant transitions.

FIGURE 1. A spectrographic illustration of the incremental and holistic primes for the target word *bed* produced by an adult male speaker. This syllable contains the lax vowel /ɛ/, and the final consonant was unreleased. The arrows below the *x*-axis represent the incremental and holistic prime durations of 62 ms and 253 ms, respectively. To help clarify the fact that the two types of primes—holistic and incremental—did not in any way temporally overlap, two different indexes of the beginning point or time zero can be seen on the *x*-axis. For the incremental prime, 0 is used to demark the beginning or 0 time point; for the holistic prime, 0′ demarks the beginning or 0 time point. Thus, the beginning or 0 time point for the holistic prime does not correspond to the 0 time point for the incremental prime.



Stimulus Onset Asynchrony

Time between prime onset and picture onset (i.e., stimulus onset asynchrony) was 600 ms. Related pilot work (i.e., Melnick et al., 2003) indicated that stimulus onset asynchronies of ≤400 ms were too distracting for preschool age children. The selection of 600 ms also precluded the possible confound of a temporal overlap between presentation of the auditory prime and presentation of the picture.

Auditory Priming Conditions

There were three auditory priming conditions: (a) neutral, (b) incremental, and (c) holistic. For each condition, participants were shown the same set of 12 target pictures one at a time in a randomized order, with the onset of subsequent pictures dictated by the participant's response, which activated a gating switch on a microphone linked to the desktop computer. A brief 1- to 2-min break occurred between each condition to permit the preparation of the next condition with the order and sequence of each priming condition presented in a counterbalanced manner within and across participants.

Neutral prime condition. Participants were presented a neutral prime 600 ms prior to picture presentation. The neutral prime consisted of a 100-ms, 1-kHz beep presented at 45 dB SPL free-field from a pair of standard computer speakers. The computer recorded each participant's SRT and presented the following target or picture 1,500 ms after the participant's response.

Incremental prime condition. Participants were presented the incremental prime 600 ms prior to picture presentation. The average length of the incremental prime was 105 ms (SD = 43). These primes consisted of the target's initial consonant(s) and two to six complete glottal pulses (M = 4, SD = 2) of the transition into the following vowel (see Table 2). These primes were "incremental" because they were composed of only the initial sound segment of the word and the first two to six glottal pulses of the vowel transition, information that is very salient to sound segment perception of the onset or beginning of a word. Thus, the perceptual emphasis of the incremental prime was the initial sound in the word, and this segmental information was clearly differentiable from the syllabic cues of the holistic prime. It was predicted that these primes would facilitate a processing mode sensitive to a unit of speech at the segmental (phone) sound level.

Holistic prime condition. Participants were presented the holistic prime 600 ms prior to picture presentation. The average length of the holistic prime was 302 ms (SD = 69). This auditory stimulus included all the acoustic information of the target word except for the initial consonant and two to six glottal pulses of the transition to the following vowel (see Table 2). Thus, the holistic prime included the entire word minus the onset cues that were included in the incremental primes. These primes were "holistic" because they included a portion of the initial transition and all of the nucleus and final transition (i.e., coda) to allow for the processing of the global shape of the syllable unit of speech. Perceptually, the holistic prime was heard as the entire word except the initial sound segment. It was predicted that these primes would facilitate a mode of processing sensitive to a unit of speech of at least syllable size.

Data Preparation Before Analysis

Criteria for Data Exclusion

Errors. Picture-naming responses were regarded as errors and *not* included in the final data corpus if the participant produced a response that deviated in *any* way from the picture's "intended name" (e.g., "ba" for "ball") and/or was associated with any type of speech disfluency (e.g., "um…car" or "c-car"). If more than 35% of responses were errors, the participant was excluded. This 35% criterion is based on previous priming protocols used to study preschool children (e.g., Anderson & Conture, 2004; Melnick et al., 2003). Regarding the exclusion of speech disfluencies, the first author and another certified speech-language pathologist who was trained in both on- and off-line transcription of stuttering observed each child's response on-line and kept a written transcription of any potential silent or audible speech disfluencies. The video recording of each child was then observed by the first author and the same trained doctoral student to allow for maximum assurance that no disfluent naming responses were included in the final data corpus.

Lost picture-naming responses. Reactions times that were non-speech-related were considered "lost picture-naming responses" (see Brooks & MacWhinney, 2000) and were not included in the data analysis. Specifically, responses preceded by, or associated with, any type of extraneous noise (e.g., tongue click) that inadvertently triggered the gating switch on the voice-activated microphone as well as responses that failed to trigger the gating switch (i.e., participant responded too softly) were excluded.

Outliers. After removing the lost picture-naming responses, the remaining speech-related reaction times that were greater or less than 2 SDs above or below the mean of all participant responses for that particular condition were removed. These values were removed because they were most likely associated with inattention and/or "fast guessing" and, thus, not reflective of the linguistic process being studied (see Ratcliff, 1993, for various analytical procedures for dealing with reaction time outliers).

Application of Criteria to Exclusion of Participants

Although the final data corpus was based on 52 participants (CWS = 26 and CWNS = 26), to achieve that number a larger pool (n = 65, consisting of 31 CWS and 34 CWNS) was initially considered. The difference between the "initial group" (n = 65) and the final participant group (n = 52) was due to the application of the above exclusion criteria, which are explained below.

CWNS. From an initial group of 34 CWNS, 4 participants (3 who were age 3, and 1 who was age 5) were excluded because one or more of their standardized test scores fell below the 20th percentile criterion. Of the remaining 30 CWNS, 4 additional participants (2 per age group) were excluded because more than 35% of their naming responses were considered errors in at least one of the three priming conditions. The remaining 26 CWNS (N = 13 per age group) provided 936 picture-naming responses (12 picture-naming responses per condition × 3 priming conditions × 26 participants). Within the 936 available picture-naming responses produced by the 26 CWNS, 21 (2.2%) were considered to be lost picture-naming responses (as described above). Forty-nine (5.2%) of the 936 speech-related picture-naming responses were considered to be outliers and were excluded because the SRT was ±2 SDs from the mean for all CWNS. This finding of 5.2% outliers is within Ratcliff's (1993) guideline of ≤12% for elimination of reaction time outliers. Based on the criteria for identification of errors, 31 of the 936 picture-naming responses were excluded because (a) 58.1% (18/31) deviated from the picture's intended name and (b) 41.9% (13/31) were associated with speech disfluency. Thus, the final data corpus for the 26 CWNS consisted of 835 fluent, accurately named, usable picture-naming responses.

CWS. From an initial group of 31 CWS, 3 participants (1 of the 3-year-olds and 2 of the 5-year-olds) were excluded because one or more of their standardized test scores fell below the 20th percentile criterion. Of the remaining 28 CWS, 2 additional participants (1 from each age group) were excluded because at least 35% of their naming responses were considered errors in at least one of the three priming conditions. The remaining 26 CWS (13 from each age group) provided picture-naming responses for 936 picture-naming responses (12 picture-naming responses per condition × 3 priming conditions × 26 participants). Within the 936 available picture-naming responses produced by the 26 CWS, 37 (4.0%) were considered to be lost picture-naming responses and were excluded from the data corpus. Thirty-eight (4.1%) of the 936 speech-related picture-naming responses were considered to be outliers and were excluded from the final corpus because the SRT was ±2 *SD*s from the mean for all CWS. Our finding of 4.2% outliers is within Ratcliff's (1993) guideline of <12% for reaction time outliers. Based on the criteria for identification of errors, 59 of the 936 picture-naming responses were excluded because (a) 50.9% (30/59) deviated from the picture's intended name and (b) 49.1% (29/59) were associated with speech disfluency. Thus, the final data corpus for the 26 CWS consisted of 802 fluent, accurately named, usable picture-naming responses.

Measurement Reliability

Response accuracy. For accuracy of the fluent responses (i.e., those fluent responses correctly articulated and named), intrajudge measurement reliability was conducted by having the first author transcribe naming responses from 6 randomly selected CWS (3 from each age group) and 6 randomly selected CWNS (3 from each age group) across each of the three priming conditions (12 responses × 3 conditions × 12 participants = 432 responses) on two occasions separated by a period of 1 month. For interjudge reliability, a certified speech-language pathologist transcribed the naming responses across each of the three conditions for these same 12 participants. Cohen's kappa statistic was used to measure reliability for these categorical judgments, because this relatively conservative measure factors out chance agreement. Intra- and interjudge measurement reliability for response accuracy using Cohen's kappa was ≥.91, which is considered to be excellent, after Fleiss (1981).

Identification of moments of stuttering and other speech disfluencies. Reliability testing for judgments of moments of stuttering and other disfluencies was accomplished by having the first author and another certified speech-language pathologist trained in disfluency analyses independently analyze the audio/video recordings of the entire 300-word conversational sample between 6 randomly selected CWS participants (3 from each age group) and their parents and 6 randomly selected CWNS participants (3 from each age group) and their parents. The conversational speech samples of these 12 randomly selected participants included a total of 2,400 words and represented 15% of the total data corpus (there were 15,600 words total for all 52 participants). For intrajudge reliability analyses, the first author reobserved the videotape recordings of the 12 randomly selected children on two separate occasions, separated by a period of 1 month, and reidentified all instances of stuttering and other disfluencies within each sample. For interjudge reliability, the first author and a certified speech-language pathologist independently observed the same 12 recordings and then identified all moments of stuttering and other disfluencies. The following measurement reliability index was used to calculate the intra- and interjudge reliability percentages: (A + B)/N × 100, where A = number of words judged stuttered on both occasions, B = number of words judged nonstuttered on both occasions, and N = total number of responses. Intra- and interjudge measurement reliability for other disfluencies was 96% and 92%, respectively. Intra- and interjudge measurement reliability for moments of stuttering was 95% and 87%, respectively.

Results

Descriptive Measures

Stuttering-like Speech Disfluencies

An analysis of variance (ANOVA) was used to verify that the talker groups differed in mean production of stuttering-like disfluencies. As expected, based on subject selection criteria, CWS exhibited significantly more stuttering-like disfluencies during the 300-word conversational speech sample than CWNS, $F(1, 50) = 89.078$, $p < .0001$.

Speech and Language Abilities

Although all participants scored at or above the 60th percentile on a variety of standardized speech-language tests (e.g., PPVT–III, EVT, and GFTA), a multivariate ANOVA (Bonferroni corrected) revealed significant between-group differences on one of these measures of speech and language. Specifically, CWS scored significantly lower than CWNS on the receptive portion of the TELD–3, $F(1, 52) = 12.976$, $p < .001$. To address the possibility that this difference may have affected the noted SRT differences between talker groups, we employed an analysis of covariance (ANCOVA) as this permits statistical control for between-group differences in speech-language abilities (as measured by the standardized test) by taking into account the relationship between performance on this subtest and the participants' SRTs for the priming conditions. Results indicated that the effect of the TELD–3 receptive subtest as a covariate was nonsignificant (p values ranging from .287 to .998) for both within talker groups between age groups across conditions and between talker groups within age groups across conditions (see Table 3). Thus, appropriate inferential parametric analysis (i.e., ANCOVA) indicated that this difference in performance on the TELD–3 receptive subtest did not influence the study's main dependent measure of SRT.

Picture-Naming Response Accuracy

A mixed-model ANOVA was used to evaluate response accuracy (i.e., fluent, correctly articulated, accurate production of target word for picture) using the between-subjects factor of talker group (i.e., CWNS vs. CWS) and the within-subjects factor of presentation condition (i.e., neutral, holistic, and incremental). No significant differences were found in response accuracy for all participants among the presentation conditions, $F(2, 100) = 1.482$, $p = .232$, and there was no significant interaction between response accuracy and talker group, $F(2, 100) = 0.907$, $p = .407$.

Experimental Measures

To measure differences in holistic versus incremental processing for 3- versus 5-year-old CWS and CWNS, a difference score was calculated for each participant's SRT in the holistic minus the neutral conditions (i.e., SRT holistic difference score = holistic SRT – neutral SRT) and in the incremental minus the neutral conditions (i.e., SRT incremental

TABLE 3. Results of analyses of covariance with EVT standard scores and TELD–3 receptive language (TELD–3R) standard scores run as covariates within and between talker groups.

Talker group	Age group (years)	Condition	Covariate	F ratio	Significance
CWS	3 vs. 5	Holistic	TELD–3R	0.091	.765
CWS	3 vs. 5	Incremental	TELD–3R	1.186	.287
CWNS	3 vs. 5	Holistic	TELD–3R	0.000	.998
CWNS	3 vs. 5	Incremental	TELD–3R	0.518	.479
CWS vs. CWNS	3	Holistic	TELD–3R	0.561	.462
CWS vs. CWNS	3	Incremental	TELD–3R	0.067	.798
CWS vs. CWNS	5	Holistic	TELD–3R	0.488	.492
CWS vs. CWNS	5	Incremental	TELD–3R	0.749	.396

difference score = incremental SRT – neutral SRT). These differences can be interpreted as follows: (a) a positive (+) difference indicates that the participant's SRT was slower in the respective priming condition than the neutral condition, indicating that the priming condition did not facilitate a faster SRT, and (b) a negative (–) difference score indicates that the participant's SRT was faster in the respective priming condition than the neutral condition, indicating that the priming condition did facilitate a faster SRT. A mixed-model ANOVA with SRT as the dependent variable, condition as the repeated measures factor, and age (3- and 5-year olds) and talker groups (CWS and CWNS) as the between-subjects factors was completed (see Figures 2 and 3).

The results of the ANOVA revealed significant main effects of age group, $F(1, 48) = 4.577$, $p = .038$, talker group, $F(1, 48) = 8.970$, $p = .004$, and condition, $F(1, 48) = 5.638$, $p = .030$. Results also revealed significant two-way interactions of Condition × Talker Group, $F(1, 48) = 30.078$, $p < .0001$, and Condition × Age Group, $F(1, 48) = 27.065$, $p < .0001$. The Condition × Talker Group × Age Group interaction was nonsignificant, $F(1, 48) = 1.528$, $p = .222$. Results further indicated that there was not a significant interaction between age and talker group, $F(1, 48) = 0.588$, $p = .447$. Follow-up analyses revealed that for the incremental priming condition there was a significant difference in SRT between 3- and 5-year-old groups, $F(1, 50) = 18.785$, $p < .0001$, and there was a significant difference between CWNS and CWS for both the incremental, $F(1, 50) = 15.405$, $p < .0001$, and holistic, $F(1, 50) = 6.685$, $p = .013$, priming conditions. There was no significant difference in SRT between 3-year-olds and 5-year-olds for the holistic priming condition, $F(1, 50) = 2.636$, $p = .111$.

Discussion

Main Findings: An Overview

The present study yielded four main findings. First, there was no difference between 3-year-olds and 5-year-olds for the holistic condition, but there was a significant difference between 3- and 5-year-olds for the incremental condition. Second, SRT differed in the condition depending on the talker group or age group. Third, CWS differed from CWNS for both priming conditions, with CWS being faster in the holistic condition than CWNS and slower in the incremental

FIGURE 2. Speech reaction time (SRT) difference scores in milliseconds for the holistic minus the neutral priming conditions and the incremental minus neutral priming conditions for 3-year-old children who stutter (CWS) versus 3-year-old children who do not stutter (CWNS).

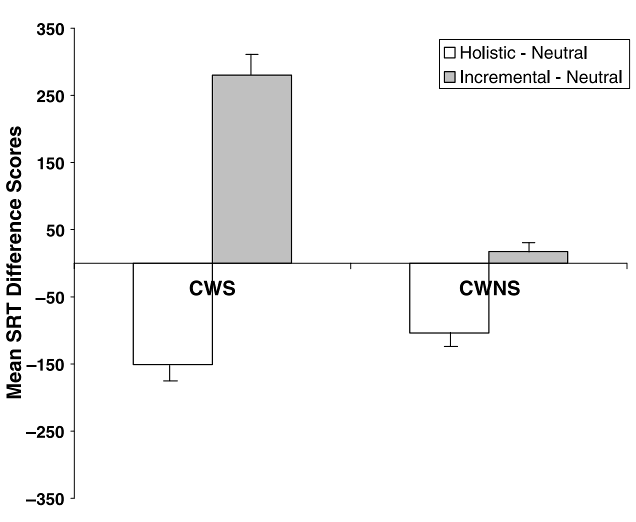
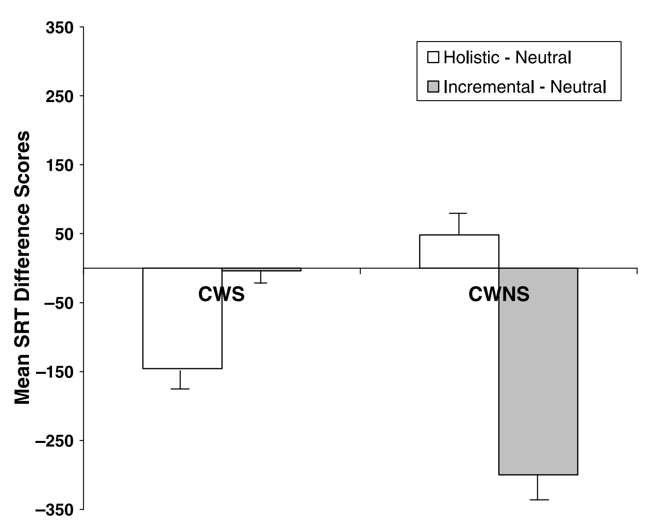


FIGURE 3. SRT difference scores in milliseconds for the holistic minus the neutral priming conditions and the incremental minus the neutral priming conditions for 5-year-old CWS versus 5-year-old CWNS.



condition than CWNS. The fourth and final main finding was that there was not a significant age by talker group difference. The discussion to follow will focus on each of these four main findings.

Finding One: Age

The lack of significant difference between the 3- and 5-year olds for the holistic condition is largely driven by the CWS data, given that there was not much of a shift in SRT from age 3 to age 5 for CWS. That is, for CWS, from age 3 to age 5, their fastest SRT was in the holistic condition, and the SRT for that condition remained fairly similar between 3 and 5 years of age. The presence of a significant difference for the incremental condition between these two age groups lends support to the hypothesis that with development, young children have to learn to increasingly distinguish among phonologically similar sequences in the decoding and encoding of language. Specifically, researchers have suggested that during early language development, rather than learning phonemic contrasts, children are more focused on recognizing and producing whole words (Jusczyk, 1992; Walley, 1988, 1993). Thus, the early words of young children appear to be encoded holistically, including such properties as prosodic features and syllable shape, rather than encoded segmentally as specific phonetic features represented in individual sound segments (Charles-Luce & Luce, 1990; Jusczyk, 1992; Studdert-Kennedy, 1987; Walley, 1993). However, the increasing size of the child's vocabulary is thought to require the child to shift attention from the whole word to individual phonemes in order to better differentiate among phonologically similar representations (Walley, 1988, 1993). It is thought that these incremental cues allow for more efficient access to a growing lexicon of words that differ by relatively few sound segments.

Finding Two: Talker Group

For the present study, the previously discussed shift from 3 to 5 years of age from holistic to incremental processing was more apparent in CWNS than CWS. That is, CWS as a group were faster than CWNS in the holistic condition and slower than CWNS in the incremental condition. The reasons for this developmental difference between CWS and CWNS may be attributed, but not limited, to developmental differences in phonological encoding between CWS and CWNS.

To that end, Brooks and MacWhinney (2000) argue that the inability to process incrementally may result in a fluency breakdown in spontaneous speech production. Thus, an encoding strategy that can handle X number of speech-language units/second may be apt to break down when engaged in communication that typically requires an encoding strategy capable of handling $X + N$ speech-language units/second. It is important to note that our description of the continued use of holistic processing as a "more immature" or "less developed" phonological encoding strategy neither explicitly nor implicitly indicates that the child (who does or does not stutter) has difficulty articulating speech sounds. Rather, this description suggests that the underlying covert learning, planning for, and/or selection of these speech sounds may remain mainly at a whole-word level rather than shifting to individual sounds despite the child's increasing cognitive/linguistic/communicative requirements. Thus, the lack of congruity between the child's relatively immature, inefficient processing abilities *and* the relatively fast rate at which longer, more complex utterances must be processed may increase the probability the child will exhibit speech disfluencies. Support for this speculation is found in the research related to the length and complexity of stuttered productions.

Research has indicated that stuttering varies depending on the number and complexity of the speech units produced (see Bloodstein, 1995, chap. 7, for review). For example, when examining fluent speech ranging from the single word level to the sentence level, Wolk (1990) reported that CWS produce significantly fewer speech disfluencies during single word than sentence level productions. Likewise, Melnick et al. (2003) reported that among 3,240 single word picture-naming responses produced by 18 CWS and 18 age/gender-matched CWNS, only 1% ($N = 33$) were disfluent. Similarly, in the present study, only 3.2% ($N = 29$) of the 899 single word picture-naming responses produced by the 26 CWS were disfluent. Furthermore, Zackheim and Conture (2003) reported that instances of stuttering are most likely to occur in utterances above a child's mean length of utterance as well as in utterances that are more complex in nature.

If, as present results suggest, most CWS are employing a holistic method of processing, then this means of processing should support reasonably fluent speech during the production of single word responses. However, increasing requirements for children to use longer and more complex utterances over time cannot be sufficiently met by predominant use of a holistic method of processing. Thus, for at least some CWS, the "mismatch" between the dynamically and rapidly changing linguistic components of their increasingly longer, more complex utterances and their continued reliance on a less developed, less mature phonological encoding system may further exacerbate underlying difficulties with speech-language planning and production. Perhaps this mismatch is similar to that experienced by children who present with phonological delay.

Storkel (2004) suggests that children with phonological delays may present with a common sound sequence disadvantage in that those words that are more similar to other words in the child's lexicon are more difficult because of his or her inability to distinguish between the segments within these similar words. Rather than enhancing lexical acquisition as it does in the case of typically developing children, words with common sound sequences may in fact inhibit lexical acquisition for children with phonological delays. Specifically, the connectivity that would be expected to occur between words of similar sound sequences does not occur, and consequently the child's lexical neighborhood is not efficiently organized. Interestingly, Walley, Metsala, and Garlock (2003) argue that in order to be able to differentiate between common sound sequences among words, a child must be able to employ an incremental processing strategy. If CWS are delayed in their shift to incremental processing, then it seems reasonable to assume that they may also present with a common sound sequence disadvantage—a disadvantage that may contribute to their inefficiency in phonological encoding, which in turn may contribute to their inability to maintain fluent speech production.

Finding Three: Condition

Results indicated that SRT significantly varied between the holistic and incremental conditions. This finding supports the assumption that these priming conditions differed, allowing for the speculation that the two conditions tapped into distinctive processing strategies. If no such differences were found, it would not be possible to argue that depending on the child's phonological processing strategy the condition would either facilitate or inhibit the child's naming of the picture. Thus, this finding provides important support for the distinctive properties assessed by the incremental and holistic primes illustrated in Figure 1 and Table 2.

Finding Four: Age by Talker Group

The finding of the nonsignificant interaction was expected given the prediction that 3-year-old CWS would not differ from 3-year-old CWNS. In order for this interaction to be significant, the talker groups would have had to have significantly differed at both age 3 and age 5. Findings indicated that by age 5 both CWS and CWNS demonstrated increases in the speed of naming in the incremental condition. However, CWS continued to display faster SRT in the holistic prime condition at age 3 and age 5. By comparison, CWNS appeared to shift from being faster in the holistic condition to being faster in the incremental condition. These findings lend further support to the hypothesis that delays and/or difficulties establishing more mature phonological encoding processes may be associated with childhood stuttering.

Nevertheless, the question remains as to why there were some CWS ($N = 3$) who by age 5 were faster in the incremental than the holistic condition. The answer may be that despite the fact that these difficulties with phonological encoding may improve with time (Paden, Yairi, & Ambrose, 1999) and the child may eventually develop an incremental method of processing, the persistence of holistic processing at a later age than is developmentally appropriate may continue to affect their ability to establish fluent speech-language production even after a shift to incremental processing has been made. Such speculation is supported by the "gone but not forgotten" hypothesis (Conture & Zackheim, 2003) which conjectures that the initiating events contributing to stuttering in childhood may be gone but not forgotten in older children and adults in the form of temperamentally linked behavioral factors and learned maladaptive compensatory strategies. Recent findings appear to lend support to this theory. Results from Paden, Ambrose, and Yairi (2002) indicated that initial differences in phonological abilities between children who recovered from stuttering and children with persistent stuttering decreased over time. Perhaps any initial difficulties with phonological encoding including the shift from holistic to incremental processing disappeared, but the reactions to this difficulty and the compensatory strategies remained. This argument may explain the individual data from the present study indicating that a few of the CWS were faster in the incremental condition than holistic condition by age 5. Thus, for these CWS, there was not only an appropriate phonological maturation, but also a critical change in any negative reactions or compensatory strategies based on the phonological difficulty.

Alternative Explanations

The above speculation appears to account for the current findings; however, there are at least three alternative explanations.

Incremental versus holistic primes. Although both primes contain static (consonant noise, resonant onsets, and/or vowel target) and dynamic (formant transition) cues, one could argue that the incremental prime was more dynamic (i.e., substantial change over a relatively short duration) in nature whereas the holistic prime was more static over a longer period of duration (i.e., little or no change). Malech and Ohde (2002) found that children use dynamic information less than adults do. Perhaps the differences between the two age groups are related to developmental differences in cue weighting (i.e., the theory that during the perception of sounds listeners may not make equal use of all the acoustic cues available; Ohde & Haley, 1997). One must view this interpretation with caution, however, given that other studies (e.g., Ohde, Haley, Vorperian, & McMahon, 1995) have shown that children were as accurate with dynamic as with static cues.

Stimulus onset asynchrony. The stimulus onset asynchrony remained constant across all conditions, but there was more lag time between prime and picture onset for the incremental than the holistic condition (an event that was identical for all participants in both talker groups). This difference in time might have resulted in temporal decay or rather the loss in the ability of the prime to "speed up" the access of the target word. Interestingly, however, present results appear to indicate that both incremental and holistic primes can potentially speed up the naming response. Furthermore, if this "temporal decay" was more of a factor for the incremental condition, it clearly had minimal impact as the 5-year-old CWNS participants exhibited faster SRT during the incremental than the holistic condition.

Speech and language abilities. On the TELD–3 receptive subtest, both CWS and CWNS performed well within normal limits, but the CWS performed significantly lower than the CWNS. One might falsely assume that this difference may have contributed to the differences noted in the experimental conditions between CWS and CWNS. However, this subtest was administered as part of our exclusionary criteria. Thus, results of this subtest and the other standardized tests administered were not treated as dependent variables, nor were they part of our experimental analysis. Furthermore, this difference is consistent with differences on standardized speech-language tests reported in similar studies (Anderson & Conture, 2004; Arnold, Conture, & Ohde, 2005; Pellowski & Conture, 2005). Nevertheless, to prevent any false assumptions, we investigated what influence, if any, the performance on the TELD–3 receptive subtest had on the dependent variable (i.e., SRT). As results indicated, the effect of this subtest as a covariate was nonsignificant. Therefore, the SRT differences noted between CWS and CWNS for the priming conditions were not related to differences seen on the TELD–3 receptive subtest.

Clinical Implications

Recent research (Walley et al., 2003) suggests a strong relationship between phonological awareness, the ability to

analyze the sound structure of language (Metsala, 1999), and the ability to phonologically encode in an incremental manner. If there is a relationship between the segmental structuring of the lexicon and the ability to segment sounds in words, then facilitating the development of phonemic awareness in a child should in turn facilitate the child's shift to incremental processing. Although this may not be the typical process of development, those children who are having difficulty structuring their lexicon on their own may receive benefit from exposure to phonemic awareness strategies. Furthermore, the present theoretical argument and associated findings suggest that the use of incremental encoding supports the maintenance of fluency beyond the single word production level. Therefore, any strategy that enables the child to shift from holistic to incremental processing should in turn facilitate a notable decrease in the child's production of speech disfluencies. Treatment protocols for young CWS should consider including the use of phonologically based treatment strategies. The use of such strategies should help CWS to use more efficient phonological storage and access of words and, as a result, facilitate their ability to produce and maintain fluent speech produc-
tion. To date, we have tested this theory with a total of 7 CWS, with results indicating that exposure to phonemic awareness strategies does facilitate a shift to incremental processing and does in turn appear to facilitate a significant decrease in disfluent speech (Zackheim, Conture, Ohde, Graham, & Johnson, 2003). However, additional research with more participants is needed to provide an initial evaluation of the validity of this proposal relative to intervention efficacy with young CWS.

Conclusion

Results from the present study indicate that from 3 to 5 years of age, CWNS shift from being significantly faster in the holistic priming condition to being significantly faster in the incremental priming condition. Conversely, the majority of 3- and 5-year-old CWS continue to exhibit faster SRT in the holistic than the incremental condition. Most preschool CWS appear delayed in making the developmental shift in phonological encoding from holistic to more incremental processing. If this is so, preschool CWS may require additional acoustic-phonetic information to plan and produce faster naming responses at a later age than CWNS. Perhaps, therefore, this requirement contributes to the difficulties CWS have establishing fluent speech-language production, particularly as they are required to process and produce longer, more complex utterances as they develop cognitively, communicatively, and linguistically.

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