The Effects of Frequency Altered Feedback on Reading Comprehension Abilities

of Normal and Reading Disordered Children

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The development of reading in children appears to result from the coordination of several interrelated, but distinct sub-processes. Evidence suggests that phonological processing abilities are primary for the development and use of word decoding, letter naming and serial naming [25]. However, the degree and level of semantic activation, phonological information processing and orthographic decoding are related to reading rate and comprehension [28]. Thus, deficiencies in reading must be carefully examined to determine which sub-processes may be involved in deterring successful completion of the task. Once the areas of difficulty are determined, treatment programs must be designed to specifically target the deficient sub-processes in order to have maximum success. Alterations in auditory feedback appear to impact the neurobiological functions related to phonological processing and positively affect the reading abilities of some children diagnosed with reading disabilities [4, 13]. Therefore, this study sought to further examine the facilitory effects of one type of auditory feedback, frequency altered feedback (FAF), on reading abilities in children diagnosed with reading disabilities.

During the emerging literacy stage of beginning reading, the phonological decoding strategy is considered to be the primary strategy [25]. This method of decoding is an indirect route in which the user relies on their knowledge of the language sound system and their ability to manipulate and segment individual sounds or clusters of sounds into whole words requiring "at least three components – general cognitive ability, verbal memory, and speech perception" [1, 3, 15, 16, 19]. Additionally, it has been shown, through the implementation of rapid automatized naming (RAN) tasks, that phonological processing abilities correlate strongly with reading ability, and discriminate below from above average readers on variables of reading comprehension, word reading,

and spelling [28]. Thus, when readers have deficient phonological decoding skills, a significant impact on reading efficiency and comprehension may result [5,6] which is referred to as the phonological deficit theory [17].

Although the phonological deficit theory is able to account for many individuals with reading disabilities, it may not account for all individuals. Wolf and Bowers [31] forwarded a theory on reading disorders termed the double-deficit hypothesis. This theory rejects the claim that difficulties in lexical decoding are a result of poor phonological skills. Rather, the authors posit that phonological decoding anomalies and deficits in lexical access are functionally disparate processes, independent in their contributions to reading and decoding. According to the double-deficit hypothesis, children with dyslexia may suffer from deficits in phonological decoding, lexical decoding, or a combination of both [29, 31].

While considerable behavioral data support the double-deficit hypothesis, a large literature exists providing convincing data supporting a central, neurobiological and physiological etiology for specific reading disorders implicating a primary deficit in phonological processing [21]. The application of functional magnetic resonance imaging technology has shown differences in the temporo-parieto-occipital cortical sites between dyslexic and normal reading children. Specifically, anomalies were noted in the left-hemisphere parieto-temporal and occipito-temporal cortical fields during a variety of tasks that placed exceedingly complex and progressive demands on phonological processing mechanisms.

Evidence exists mapping compensatory neuro-processing mechanisms in reading disordered children. It appears that older people with dyslexia engage both the left and

right inferior frontal gyrus during difficult phonological processing tasks, while younger children fail to do so [26]. Such data suggest that reading disordered adults recruit compensatory, homologous, right hemisphere region activation to help compensate for left hemisphere activation anomalies. Additionally, analysis of the relationships between reading skill and cortical activation has shown that a negative correlation exists between right occipto-temporal region activation and reading skill, suggesting that disordered readers rely on right, occipito-temporal regions for reading processes, as compared to the left hemispheric analogue reading network employed by normal readers. Even though cortical reading centers in reading disordered children appear disrupted, considerable levels of neuro-plasticity are evident in such populations, given the application of effective reading intervention programs.

A number of treatment programs exist for children diagnosed with reading disorders [14, 28, 31] including the application of altered forms of auditory feedback. Evidence suggests that disrupted or altered auditory feedback impacts directly on phonological coding mechanisms underlying reading functions [4], providing support for the existence of the double-deficit hypothesis since reading improved when reliance on phonological coding operations were reduced.

Kershner, Hadfield, Kershner, and Cooke [13] proposed that a modified voice feedback (where high frequency spectral information was amplified) during a timed naming task improved letter-naming speed in a select sub-type of learning disabled children. For a subtype of reading disordered children exhibiting anomalies in speech-monitoring, high frequency filtering in the auditory feedback network effectively stimulated letter-sound memory associations that contribute to fluent reading. However,

the frequency modification significantly imposed a disruptive effect on disabled readers with intact auditory functioning, concluding that "in absolute terms, the FM effect was small" and that "additional research is needed to determine actual performance benefits of FM as a remedial intervention." Finally, while the authors proposed that their findings might suggest the presence of a physiological anomaly in the auditory pathways or cerebral hemispheres, it may not be possible to speculate the exact location of a lesion. At best, the data suggest certain reading disorders result from a delay in development or suggest the presence of some form of neuropsychological discrepancy.

In an investigation designed to improve functional reading capacity in reading disordered children, Brezinitz [4] employed auditory masking and reading acceleration. Results showed that reading acceleration improved reading performance in both normal and reading disordered children. However, the masking condition was shown to enhance the dyslexic children's comprehension, while proving disruptive to the normal readers. It was argued that auditory masking reduces the effects of impoverished phonological processing in reading disordered children, enabling a more effective utilization of orthographic codes, enhancing top-down contextual effects for the reading disordered children. In addition, oral reading errors in the reading disordered children decreased while reading speed increased. It was suggested that the presence of exogenous, auditory speech-competition influenced the "distribution of processing resources" in reading disordered children, allowing for reallocation or differential access and reliance on phonological, orthographic, and semantic processing mechanisms. While the underlying neural mechanicals accounting for their results were not speculated, it remains possible that modifications imposed on the auditory feedback system underlying sensory-motor

encodings of speech output and processing of written material result from alterations in the signature of those cortical subsystems with regulatory control over the central, neuronal mechanisms subserving language and speech production events, stimulating more normalized reading functions.

Frequency altered feedback (FAF) also has proven to influence hemispheric activity of cortical fields associated with language production significantly impacting speech production mechanisms in populations of people who stutter. Specifically, an FAF signal was shown to alter qEEG activity in posterior cortical regions corresponding to the language neural substrate in people who stutter, possibly reflecting changes in neurogenerator status or dipol activity underlying verbal processing [18]. The cortical region enhancing effects may be due to the acoustic structure of the FAF signal. That is, the FAF signal shares frequency, time and amplitude characteristics of the human speech signal, albeit one-half octave higher than the speaker's voice fundamental frequency. As such, a speaker processes FAF as an endogenously produced "second-speech" signal, which has been shown to produce robust speech-production enhancing effects [11,12, 23, 24]. As a result, its application to the remediation of persons with reading disabilities appears warranted. Therefore, the purpose of the current investigation was to study the effects of frequency altered feedback (FAF) on reading functions in children with diagnosed reading disorders.

Methods

Participants

The participants were 27 students, 15 normal reading sixth grade students and 12 sixth grade students attending local eastern North Carolina middle schools diagnosed by

their school as being reading delayed and were enrolled in a traditional reading program with phonological processing serving as the primary emphasis for habilitation. Each participants' overall reading ability score on the Woodcock Johnson Reading Mastery Test-Revised (WRMT -R) [30] determined reading ability. Normal reading ability was defined as an age appropriate score. Delayed reading ability was defied as one or two years delayed relative to the age appropriate score. All participants had normal bilateral hearing sensitivity as determined by a screening protocol, normal or corrected vision, as reported by their parents or school personnel, passing scores for language screening [20] and average scores for receptive one-word picture vocabulary [8].

Materials and Instrumentation

Participants read three passages from the Spadafore Diagnostic Reading Test [22], (one each at the third grade, sixth grade and ninth grade levels) under both non-altered feedback (NAF) and frequency altered feedback (FAF). Following the reading of each passage, the participant then read and responded to five multiple choice questions that assessed comprehension of the written material.

The FAF signal was delivered via a Sennheiser Communications Pocket Speech Lab (PC 130), with a Sennheiser (PC 130) headset. The device was designed to capture the participant's voice via the noise-canceling microphone (Model 116B) and fed into to the Pocket Speech Lab, which is an audio-vocal closed-loop feedback device which filters the participant's voice and produces a signal one-half octave above his normal speaking voice. The altered voice was fed back without delay. Thus, the participant heard his or her own voice through the headphones in the adjusted format in real-time. The

signal level to the earphones was adjusted to each participant's most comfortable listening level.

Procedure

After administration of the standard assessment instruments, participants were given a short break. Upon returning to the testing room, the reading tasks and conditions were explained. Two separate passages for each reading level were available as test materials, which were counterbalanced across the listening conditions and participants. All of the reading tasks and conditions were audio-and video-taped for later scoring of decoding errors.

Comprehension scores and decoding errors for each condition were determined. Comprehension scores were based on the number correct for each passage with a perfect score being five. The total number of decoding errors and the total for each type of decoding error that occurred (phonological vs. visual) for each passage was calculated for further analysis. The system employed for determining decoding errors was based on the method of Rastatter and colleagues [2, 10, 26, 27] where the sub-systems or processes underlying the recognition of visual information can be identified. Such a method allows for direct assessment of phonological processes (auditory based mispronunciations, substitutions, repetitions) and visual processing functions (visually based omissions, reversals, insertions, repetitions - errors based structural descriptions). Two individuals, trained to code the responses, were employed to analyze error types. Inter-judge error type-by-error type agreement, as indicated by Cohen's *kappa* [7] was .88. Intrajudge Cohen's *kappa* agreement was .96. *Kappa* values above .75 represent excellent agreement beyond chance [9].

Results

A three-factor mixed analysis of variance (ANOVA) was undertaken to investigate mean differences in total comprehension scores as a function of group, reading level, and auditory feedback. Significant main effects of group (F (1, 25) = 15.05, P = .007) and level (F (2, 25) = 71.03, P = .0001) were found. A significant feedback by group effect (see Figure 1) was also found F (1, 25) = 10.84, P = .003). All other interactions were not significant (p > .05). In general, as reading level increased comprehension decreased. The normal reading participants had better comprehension than the reading delayed participants. Single degree of freedom contrasts were employed to investigate the significant auditory feedback by group interaction (see Figure 1). The reading delayed participants had significantly higher comprehension with FAF as compared to NAF (p = .0002) while there was no difference between the normal reading participants in NAF versus FAF (p = .41). The reading delayed participants had significantly lower comprehension than the normal reading participants in NAF (p = .0001) while there was no difference between the groups in FAF (p = .18).

A three-factor mixed ANOVA was employed to investigate differences in mean reading errors as a function of group, reading level and auditory feedback. A significant main effect of level was found (F (2, 50) = 166.69, P = .0001). A significant auditory feedback by group effect (see Figure 2) was also found (F (1, 25) = 5.84, P = .023). All other main effects and interactions were not significant (p > .05). In general, as reading level increased errors increased. Single degree of freedom contrasts were employed to investigate the significant feedback by group interaction. The reading delayed participants had significantly more errors with NAP versus FAF (p = .0007) while there

was no difference in errors with the normal reading participants in NAF versus FAF (p = .14). The reading delayed participants had significantly more errors than the normal reading participants in NAF (p = .0095) while there was no difference between the groups in F AF (p = .61).

Errors were further categorized as visual/lexical errors, those occurring when the sight-word strategy is used, but incorrectly, phonological errors, where multiple attempts at sounding out the word into sounds or syllables are observed, but the word remains mispronounced or miscued, or errors of omission. Error-type analysis showed that 92.6% of the total errors were classified as phonological errors, with visual-lexical and omission errors occurring at a rate of 4.5 % and 2.9% respectively.

Discussion

The purpose of the current study was to investigate the effects of frequency altered feedback (FAF) on reading comprehension, error rates and error type in a group of normal and reading disordered children. The reading comprehension results showed that as reading levels increased, comprehension decreased for both groups of children. Such a finding is understandable given that the level of reading material increased to a grade level three years beyond the grade-equivalent reading comprehension level for the normal children. However, under the FAF condition, the results for the two groups were significantly different. Reading comprehension under the FAF condition significantly improved for the children with reading disorders, but no difference in performance was found for the children with normal reading abilities. Similar results were found for reading error rates. That is, while both groups committed more errors as reading level

increased, the children with reading disorders committed significantly less errors under the FAF condition than when no feedback was given. This effect was not evident for the children with normal reading levels. Instead, no difference in error rate was found under the two conditions for the normal readers. Further, under the FAF condition the number of reading errors committed by the children with reading disorders was commensurate with those committed by the normal readers. These data support previous findings indicating the positive effects of FAF and may provide implications for treatment.

Reading Comprehension

Analysis of the comprehension data revealed a significant two-way interaction between groups and listening conditions. Inspection of Figure 1 shows that, for the reading disordered children, significant differences existed in comprehension scores as a function of auditory feedback, as compared to the normal readers. Reading comprehension improved significantly when the reading disordered children read aloud under the FAF listening condition, regardless of the reading material level. In fact, reading comprehension scores improved to the level nearly identical to that obtained by the normal reading group under the FAF listening condition, evidencing a similar response archetype for the two groups of participants. Comprehension scores for the normal readers, however, did not differ significantly between the NAF and FAF listening conditions. Such a finding suggests that while FAF proved capable of improving reading comprehension in the reading disordered children, it is not capable of generating significant and parallel improvements in comprehension levels for normal reading children. Such findings are in concert with those reported in the literature [4, 13] and

suggest that reading comprehension in reading disordered children is impacted favorably by the presence of the FAF signal.

While the data clearly suggest that FAF facilitated reading comprehension of the reading disordered children regardless of reading level, the underlying central processing operations that account for the similarity in response profile for the two groups of participants under the FAF are not clear at this point. Arguably, an increase in attentional processes may have contributed to the improvement in performance for the reading delayed children, however, based on the collective findings of the reading disorders literature, it appears that the processing strategies involved in stimulating reading comprehension ability were altered by the FAF signal, and most notably by impacting the extent and/or level of access to phonological processing mechanisms [4, 19].

Breznitz [4] suggested that normal, developmental reading processes rely heavily on phonological mechanisms for processing written material. The presence of a non-congruent, auditory speech signal limited access to information processing provided by phonological decoding mechanisms for normal readers, resulting in the diminished levels of reading comprehension observed in her data. The auditory-speech competition provided in the experimental "masking" condition gained "automatic access" to phonological processing mechanisms. Such access was thought to create a resource-sharing problem within the phonological processing channels, thereby reducing reading comprehension capacity in the normal reading children.

While such a position is understandable for response conditions employing competitive, non-congruent, auditory-speech material, the FAF listening paradigm does not present a parallel listening environment. Perhaps the difference in findings between

competitive, non-congruent auditory stimulus and FAF lies in the physical characteristics of the signal, and the type of linguistic load delivered by each condition. The linguistic processing load presented under FAF is identical to the speaker's verbal output. The only alteration that occurs in feedback under FAF is that the speech signal is shifted upward one-half octave with a total harmonic distortion of less than 1%. The overall feedback is representative of a "choral speech" effect where the auditory signal presents an experience of speaking in unison with another speaker. It is suggested that the choral-speech effect provided an environment that proved to be cognitively interfacing with the intended message. As a result, FAF fails to significantly impact reading comprehension of normal readers, as the phonological processing channels are capable of operating at total capacity. That is, a second-speech signal is capable of interfacing with the cognitive effort necessary to process and comprehend written material in normal readers, while concurrently providing an enhancing comprehension effect for the reading disordered participants.

Reading Error Data

A similar pattern of results was found for the reading error data. In general, both groups of children committed significantly more errors when the reading level increased. However, the presence of FAF differentially affected the number of errors committed by the two groups of children as evidenced by the significant group by listening condition interaction. Post hoc tests showed that the reading disordered children produced significantly more reading errors as compared to the normal reading children under the NAF listening condition. However, significant differences did not occur in reading errors between groups when reading under the FAF listening condition. Such findings, as with

the comprehension data, occurred regardless of the level of reading material, suggesting further that the FAF signal facilitated a reduction in reading errors in the reading disordered children.

The error data ANOVA findings are in concert with past evidence showing improved reading comprehension occurs under conditions of auditory competition in disordered readers by reducing reading errors [4]. The current error analysis, however, does not align with the position suggesting that a lexical processing rout was accessed for the comprehension data found under FAF. Of the errors committed, 92.6% were coded as phonological processing in nature. This finding held true regardless of listening condition, comprehension level, and group. Such findings suggest that phonological coding was the primary route employed by both groups in processing the current reading material.

The error data clearly show that the reading disordering children did not alter their coding strategy while reading under FAF indicating that the phonological processing channel was not disrupted. The error pattern classification system employed in the current study has been shown to be predictive of the processing operation employed to complete the tasks demands associated with both decoding and linguistic output functions [2, 10, 29, 30]. Support for a lexical re-coding strategy theory would predict that lexical processing errors would have been expected to occur in the FAF data analysis. Such was not the case, however, and an alternate response mechanism must be held accountable for the improved reading comprehension observed under FAF.

Rather, collectively the current findings suggest that the FAF signal was facilitory in effect, stimulating those central mechanisms responsible for phonological processing.

Certainly, the current results are more congruent with the neurophysiologic literature suggesting that dyslexia represents an activation disorder within the language processing network underlying phonological procession, specifically left hemisphere posterior cortical systems. Theoretically, it stands that the FAF signal may have activated those cortical regions responsible for the relationship that has been shown to exist between lexical encoding and decoding of verbal and written material, respectively, similar to that observed in stuttering behavior [18]. While the current data suggests such may be the case, physiological evidence is called for examining the effects of FAF on cortical functions in reading disabled children reading under conditions of both NAF and FAF.

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