Critical Review: Effectiveness of EMA in improving articulatory accuracy in adults with AOS

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This critical review examined the effects of electromagnetic articulography (EMA) on articulatory accuracy in adults with acquired apraxia of speech (AOS) in six studies. All studies used a single subject n-of-1 design: multiple-baseline (4) and ABA (2). Overall, the evidence provided support for the beneficial effects of EMA in improving articulatory accuracy in adults with AOS. This is an emerging area of research that is generally explorative in nature; however, the results of these studies hold promise for the future clinical utility of EMA in treating articulation difficulties in adults with AOS.

Introduction

Acquired AOS is a neurological and sensorimotor speech disorder (Wambaugh & Mauszycki, 2011). Primary clinical characteristics for AOS include: 1) a slow speech rate causing lengthened sound segments and intersegment durations, 2) speech errors at the sound level (i.e., sound distortions and/or distorted sound substitutions), 3) fairly consistent errors in type (e.g., distortion) and location (i.e., within a word), and 4) abnormal prosody (McNeil, Robin & Schmidt, 2009). These clinical characteristics of AOS are thought to result from a deficit in the planning or programming of motor movements for speech (Duffy, 2005). Other speech behaviours that are often observed in AOS include: articulatory groping, difficulty initiating speech, perseveration, and an increase in errors as word length increases (Wambaugh, Duffy, McNeil, Robin & Rogers, 2006b).

The most common cause of acquired AOS is stroke (Duffy, 2005). Other processes, such as trauma or tumor, can damage structures in the dominant hemisphere that are involved in motor speech planning, which may also lead to AOS.

A recent systematic review of the existing research on AOS treatment found that individuals with AOS may benefit from treatment, even when AOS is chronic (Wambaugh et al., 2006b). Treatments for AOS fall into four general categories: 1) articulatory-kinematic treatments, 2) rate/rhythm control treatments, 3) intersystemic facilitation or reorganization treatments, and 4) alternative and augmentative communication approaches (Wambaugh, Duffy, McNeil, Robin & Rogers, 2006a; Wambaugh et al., 2006b). Research that has investigated articulatory-kinematic approaches accounts for the majority of the evidence base supporting treatment of AOS (Wambaugh et al., 2006b). These approaches focus on improving the spatial and temporal aspects of speech production. Within this area of research, there has been growing interest in investigating biofeedback techniques to improve articulatory accuracy in AOS. EMA involves the placement of sensors on the participant's articulators in order to track movements and present them visually on a computer screen (Katz, 2003). Participants then receive visual feedback as they attempt to move their articulators into the correct "target zone" on screen which corresponds to accurate tongue placement for a particular phoneme. Several studies have found evidence for the effectiveness of EMA in improving the articulation of individuals with AOS, (Katz, McNeil & Garst, 2010; McNeil et al., 2007; McNeil et al., 2010).

Objectives

The primary objective of this paper is to critically evaluate the existing studies on the effects of EMA on articulation in individuals with AOS. The secondary objective is to summarize the outcomes of this technique to help guide future research in this area.

Methods

Search Strategy
Computerized databases, including PsycINFO, PubMed, Web of Science, Medline and CINAHL, were searched using the following search strategy: [(electromagnetic articulography) OR (EMA) OR (visual biofeedback) OR (biofeedback)] AND [(apraxia of speech) OR (AOS) OR (apraxia)]. An examination of the reference section of articles yielded more articles for inclusion.

Selection Criteria

Studies included in this critical review were required to examine the effects of EMA on speech/articulation of adults with AOS. All patients suffered from AOS and no limits were placed on the severity of the disorder. Three patients also suffered from Broca's aphasia; one from anomic aphasia; one from mild aphasia (type unspecified); one from mild-moderate aphasia characterized by phonological paraphasias (type unspecified); one from mild-moderate aphasia (type unspecified). Only studies examining adults with AOS were investigated; however, no limits were set on other demographics (e.g., gender, culture, race, or socioeconomic status). Studies included were all conducted in North America.

Data Collection

Results of the literature search yielded six articles consistent with the selection criteria: six single subject n-of-1 design studies. The intention was to review all peer-reviewed articles that have specifically examined the effects of EMA on articulatory accuracy in AOS.

Results

Single subject n-of-1 ABA design studies.

Early studies lend support for the use of EMA to improve articulatory accuracy in AOS (Katz, Bharadwaj & Carstens, 1999; Katz, Bharadwaj, Gabbert & Stetler, 2002). Katz et al. (1999) examined the effectiveness of EMA as a means of remediating /s/ and /ʃ/ articulation deficits in the speech of a female adult with Broca's aphasia and AOS. The study design was a single subject n-of-1 ABA design, which yielded a Level of Evidence of 1. Two treatments were provided in a counterbalanced procedure within each session: 1) visually guided biofeedback of tongue tip position (experimental condition), 2) computer delivered voicing-contrast stimuli for simple repetition (foil treatment). Each experimental session included a blocked series of four tasks: silent, humming, non-word, and real-word. The data was analyzed by visual inspection of tongue-tip movement for fricative production, other kinematic measures [i.e., average tongue-tip distance travelled per target hit for whole session performance and accuracy (number of hits/total attempts) for each target hit in the non-word and real-word conditions] as well as perceptual measures (i.e., percent correct judgments at baseline, final and long-term phases).

All targeted fricatives showed improvement in perceptibility from 41% accuracy at baseline to 66% accuracy in the final session and 65% accuracy at long-term assessment 10 weeks post-therapy. This improvement was predominately attributable to greater success in producing /ʃ/. The foil treatment stimuli increased perceptibility from 61% accuracy at baseline to 72% at the final session and decreased to 64% at long-term assessment. Cochran's Q tests indicated that performance differed across the three assessment points (i.e., baseline, final, long term) for the experimental treatment (Q = 7.43, p < .025) but not for the foil treatment. McNemar chi-square tests used to analyze treatment level contrasts in the experimental data (i.e., baseline vs. final, final vs. long term, baseline vs. long term) were insignificant, likely due, in part, to small sample sizes. As a result, experimental improvement patterns could not be statistically supported. Interestingly, the authors report that greater improvement was seen for the non-speech oral motor tasks (i.e., silent and humming conditions) compared to the speech motor tasks (i.e., non-word and real-word conditions). They concluded that the findings suggest that visual kinematic feedback can be used as treatment for non-speech oral and (to a lesser extent) speech motor behaviour in adults with AOS associated with Broca's aphasia.

Katz, Bharadwaj, Gabbert and Stetler (2002) also found support for the efficacy of kinematic feedback treatment for AOS. They examined whether the use of EMA improved articulation in a male adult with anomic aphasia and mild-moderate AOS. This single subject n-of-1 ABA design study has a Level 1 of Evidence. Four frequently erred phonemes were selected for counterbalanced treatment: /ʃ/ and /tʃ/ for kinematic biofeedback treatment, and /f/ and unvoiced "th" for a control (foil) treatment that did not provide visual feedback of tongue position. In line with Katz et al. (1999), the experimental sessions consisted of silent, humming, non-word and real-word conditions. Visual inspection of tongue tip traces demonstrated a clear increase in the accuracy of kinematic movements on treated targets over the course of treatment. Two examiners who were blind to the experimental/foil treatment conditions narrowly and independently transcribed untreated items that were recorded before and after treatment. Perceptual ratings of correct productions were calculated as percent accuracy and visually inspected over baseline, treatment and maintenance phases of the study. The results revealed that the two sounds that received EMA feedback benefitted from this treatment (39% increased accuracy for /ʃ/ production, 18% for /tʃ/). The two sounds that were administered the control treatment demonstrated no improvement (0% increase for /f/ and 10% decrease for unvoiced 'th'). Six weeks post-treatment, /ʃ/ productions demonstrated lasting improvement, whereas accuracy for /tʃ/ dropped to baseline. The authors concluded that the results of this study lend support for the efficacy of kinematic visual feedback in remediating place-of-articulation difficulties in individuals with co-morbid AOS and aphasia.

Single-subject n-of-1 multiple baseline design studies
A number of single-subject n-of-1 multiple baseline design studies also provide support for kinematic biofeedback in improving speech in AOS (Katz, Garst, Carter, McNeil, Fossett, Doyle & Szuminsky, 2007; Katz, McNeil & Garst, 2010; McNeil et al., 2007). Katz et al. (2007) conducted a single subject n-of-1 multiple baseline design study (Level 1 evidence) to examine the effects of short-term EMA treatment on consonants produced by a male adult with Broca's aphasia and moderate-severe AOS. The participant used visual feedback of tongue tip movements to direct his tongue toward the "target zone" which corresponded to correct placement for particular speech sounds. A trained examiner assessed the perceptual accuracy of a probe list, which was recorded at the beginning of each session, by counting a phoneme as correct if it was produced phonemically on target and without distortion. Statistical analyses were not carried out in this study. However, visual inspection of the percent accuracy ratings at baseline, treatment, maintenance and one-month follow up revealed that both acquisition and generalization of learning to untreated speech targets occurred, though not for all treated targets. The control data suggested that improvements in treatment were not due to unassisted recovery. The authors concluded that these findings provide support for kinematic biofeedback in improving the speech of individuals with AOS. The results must be interpreted with caution, however, due to the restricted number of treatment sessions provided.

Similar results were found for Katz, McNeil and Garst (2010) whom investigated whether EMA-supplied feedback improved articulatory accuracy in a female adult with a moderate Broca's aphasia and AOS. This single subject n-of-1 multiple baseline study has a Level of Evidence of 1. Treated targets (initial /j/, medial unvoiced 'th' and initial /tʃ/) and untreated controls ('br' and 'sw') were selected. Perceptual ratings were acquired with productions marked as correct if both the targeted consonant and subsequent vowel were evaluated as intelligible and accurate. Outcome of treatment data was examined by visual inspection, and Cohen's *d* effect sizes for true baseline vs. treatment, baseline vs. post-treatment, and baseline vs. long-term maintenance comparisons. For /j/, most of the targets showed acquisition (d = 1.1 to 7.74; x = 4.24), post-treatment maintenance (d = 1.47 to 7.83; x = 4.61), and long-term maintenance (d = 1.41 to 6.09; x = 3.64). Generalization occurred for five of eight untreated stimuli (d = 1.89 to 5.20; x = 3.22), was maintained at post-treatment (d = 2.75 to 4.74; x = 3.75) and all but one of these stimuli were maintained at one-month post-treatment. Most of the unvoiced "th" targets were acquired (d = 1.26 to 3.61; x = 1.95), and maintained at one-month post-treatment (d = 2.83 to 4.05). Generalization occurred for all three untreated probes (d = 1.26 to 3.61; x = 1.31), two of which showed maintenance at one-month post-treatment (d = 0.78 and 4.05). All treated targets for /tʃ/ showed acquisition, but gains for only some of the targets (d = 2.05 to 3.06) could be attributed to /tʃ/ treatment due to generalization from previously treated /j/ and /tʃ/ containing targets. Maintenance was observed for some of these targets at one-month post treatment (d = 2.09 to 2.57). All untreated targets showed improvement and maintenance (d = 0.81 to 2.31; x = 1.26), however, the improvement was influenced by generalization from previously treated targets. The authors suggested that relatively stable baselines of the control items indicate that improvement for treated items was not a result of unassisted recovery.
The results must be interpreted with caution since a small number of stimuli were used and stimuli were not balanced across frequency conditions. The authors concluded that the results of this study yield evidence that EMA supplied feedback improved the articulatory accuracy of their participant with AOS.

The studies above demonstrate that EMA-mediated feedback can yield positive results in improving the articulatory accuracy of individuals with AOS. The studies described below provide participants with both visual biofeedback and judgments of perceptual accuracy, which result in improved articulatory accuracy in adults with AOS. McNeil, Fossett, Katz, Garst, Carter, Szuminsky and Doyle (2007) examined the efficacy of EMA-mediated feedback for the treatment of a male with mild aphasia and mild-to-moderate severity AOS. The design of this study was a single subject n-of-1 multiple baseline with a Level of Evidence of 1. During each treatment session, the participant observed traces of his tongue movement and position as he attempted to move his tongue into the target zone for each word. Feedback for both correct tongue placement and auditory perceptually accurate productions was provided. Perceptual ratings of correct productions were calculated as percent accuracy and visually inspected over baseline, treatment and maintenance phases of the study. No statistical analyses were carried out on the perceptual accuracy data. The intervention produced evidence for a treatment effect (i.e., acquisition). Relatively stable baselines indicated that the effects observed were due to treatment as opposed to other potential sources. Maintenance effects were also observed for each of the targets and generalization effects were observed for 27 untreated probes. At one-month follow up, two of the untreated words dropped below the achieved level at the end of treatment. The authors reported that the participant's treatment resulted in positive acquisition effects with generalization and high maintenance effects using kinematic accuracy plus auditory perceptual feedback.

Using a similar methodology, McNeil, Katz, Fossett, Garst, Szuminsky, Carter and Lim (2010) carried out single subject n-of-1 multiple baseline design studies of two adults with AOS to examine the effects of EMA on articulatory accuracy. Both online visual kinematic knowledge of performance (i.e., visible movement traces of the tongue-tip) and the examiner's online judgments of perceptual accuracy were provided as feedback. For both participants, visual inspection judgments and effect size calculations yielded positive acquisition effects (d = 1.05 to 7.17, x = 3.28 for participant 1 (P1); d = 0.56 to 1.80, x = 1.18 for participant 2 (P2)) and generalization to speech motor targets with similar phonetic structure (d = 0.45 to 6.08, x = 2.07 for P1; d = 1.37 to 1.47, x = 1.42 for P2) and to untreated probes (d = 0.41 to 3.10, x = 1.24 for P1; d = -0.5 to 2.37, x = 1.07 for P2). One-month post therapy, long-term maintenance of learned (d = 0.94 to 9.02, x = 3.45) and generalized effects (d = 0.73 to 12.17, x = 4.5 for similar speech motor targets; d = 0.65 to 2.93, x = 1.57 for dissimilar speech motor targets) were found for P1, but not for P2 due to attrition. The authors concluded that the results support the use of augmented movement feedback to treat speech movements in order to increase the perceptual accuracy of speech production.

Discussion

The authors of the studies reviewed above provided suggestive evidence that EMA is an effective technique in improving articulatory accuracy in patients with AOS; however, these results must be interpreted with caution due to a number of limitations and methodological issues. In many of the studies, measurements of accuracy were calculated and visual inspection of the results were carried out; however, only three of the six studies performed statistical analyses (Katz et al., 1999; Katz et al., 2010; McNeil et al., 2010). In addition, several studies lacked sufficient detail in providing a description and severity rating of AOS (e.g., Katz et al., 1999) and co-occurring speech and language problems (e.g., aphasia classification was unspecified in McNeil et al., 2010). It is important that studies examining the effects of EMA on articulatory accuracy in AOS include more detailed clinical participant information. This will allow for more systematic replication of studies across varying AOS severity levels and presentations (Wambaugh, 2006). Also, the studies reviewed lacked additional participant information (e.g., hearing, medication, cognitive functioning, etc.), except for the Katz et al. (2010) study, which included educational status.

In addition, speech motor targets varied across studies in the particular phoneme(s) targeted, as well as the specific location of the phoneme in the word (i.e., initial, medial, or final). Target selection was based on each of the participants' speech errors, which resulted in individualized, error-specific treatment. This poses a problem since it makes comparison across studies quite difficult. In terms of the type of feedback provided, gains from treatment were found in studies that used only visual biofeedback as well as studies that combined both visual biofeedback and auditory perceptual feedback. Nonetheless, it remains to be seen in future studies whether the benefit of providing both visual and auditory perceptual feedback is greater than the benefit derived from providing only visual biofeedback. Moreover, this difference in methodology across the reviewed studies is another factor that adds difficulty in making comparisons across the extant literature.

Another methodological issue is the inconsistencies in the terminology used across studies (e.g., articulatory accuracy, speech accuracy, perceptibility). The lack of a definition for the terms used made construct validity across studies questionable. In addition, only one study (Katz et al., 2002) explicitly stated that the investigators who evaluated perceptibility were blinded to the treatment conditions. Therefore, it is possible that the perceptibility results of the other reviewed studies may have been influenced by bias, which, in turn, would reduce the internal validity of the studies.

External validity may have been negatively impacted by the small sample size included in each study. Five of the studies included one participant and one of the studies included two participants (i.e., McNeil et al., 2010). Also, external validity may have been impacted by the heterogeneity of the participants and their varying presentations of AOS and co-occurring speech and language problems. This reduces the generalizability of the treatment results to the acquired AOS population as a whole. Another limitation of the reviewed studies is that most included only a small number of stimuli, thereby limiting the power of the results. Lastly, the studies were quite variable in the scheduling of treatment with regard to frequency and duration. Therefore, the optimal amount of treatment required to yield positive effects remains inconclusive.

Recommendations

There is a need for further research in this field considering the limitations mentioned above. Recommendations for future research are as follows:

- Improve rigor of methodologies by including a larger set of stimuli and larger sample sizes, and increase confidence in results by using statistical analyses whenever possible.
- Provide more detailed participant information including description and severity of AOS and co-occurring speech and language problems. As the literature in this research area continues to grow, studies should include more comprehensive participant information (e.g., hearing, medication, cognitive functioning, educational status, etc.) to examine the differential effects of these variables on treatment and to allow for comparison across studies.
- Replicate positive findings in independent laboratories and across varying AOS severity levels and presentations.
- Ensure individuals transcribing data when evaluating intelligibility are blinded to treatment conditions.
- Operationalize terms to ensure measurement of the same construct across studies and to reduce inconsistencies in the literature.

Clinical Implications

The investigation of EMA to improve articulatory accuracy in adults with AOS is an area of research that is still in its infancy. Further research is needed to address the limitations discussed above and to develop a more substantive evidence base. In addition, the high cost of EMA and the level of technical skill required to operate EMA potentially limits its use in clinical practice. However, the results of the extant literature reveal that this technology holds promise for future clinical utility.

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