Critical Review:
Intervention Guided by the Principles of Motor Learning in Individuals with Apraxia of Speech

Natalie Melick
M.Cl.Sc (SLP) Candidate
University of Western Ontario: School of Communication Sciences and Disorders

Apraxia of Speech (AOS) is an acquired speech disorder of motor planning. Literature has investigated the applicability of the Principles of Motor Learning (PML) to this population, as these principles have been well researched and successfully applied to motor learning interventions specific to limb movements. This critical review examines the applicability and effectiveness of the PML when implemented in AOS intervention, and includes five single-subject designs and one randomized clinical trial. Current research indicates that the PML produce beneficial speech outcomes in individuals with AOS. Recommendations for application to clinical practice are included.

Introduction

Apraxia of Speech (AOS) is an acquired motor speech disorder characterized by an impairment in motor planning of the speech mechanism (Mass et al., 2008). This impairment refers to a disruption in the mental representation of an intended and coordinated movement (Hula, Robin, Maas, Ballard, & Schmidt, 2008). Recent evidence shows little consensus among intervention approaches in AOS and other motor speech disorders (Bislick, Weir, & Spencer, 2012). This limited consensus may be due to a lack of research in regards to how motor learning takes place within the speech system (Ballard, Granier, & Robin, 2000). In contrast, many studies have investigated motor learning of limb movement systems in physical rehabilitation (Friedman, Hancock, Schulz, & Bamdad, 2010). Evidence suggests several principles of motor learning (PML) promote lasting improvements in an individual's ability to perform motor skills (Friedman, Hancock, Schulz, & Bamdad, 2010). As these PML apply to limb movements, it is probable that these principles could apply to the speech system (Ballard, Maas, & Robin, 2007).

Studies have investigated the application of these principles in AOS interventions (Friedman et al., 2010). The PML, as summarized by Mass et al. (2008) (Appendix A), are divided into two conditions of practice, acquisition and retention. Factors specific to the acquisition phase of motor learning enhance motor performance throughout practice, but ultimately interfere with long-term motor learning. Therefore, these factors are to be applied only during the initial teaching of a skill, to ensure that intervention targets can be produced under optimal practice conditions. Once acquisition of a skill is demonstrated, factors of the retention phase of motor learning are to be employed. Literature shows that these factors cause permanent change in an individual's ability to execute a motor movement (Mass et al., 2008).

Despite vast evidence supporting the use of these PML in motor limb learning, there is little empirical agreement to support or disprove these parameters when treating the motor planning impairments of AOS (Ballard et al., 2000). Understanding how PML can be used to develop effective intervention for AOS could be very useful in allowing health care providers to deliver the best possible treatment for individuals with AOS.

Objectives

The primary objective of this paper is to critically evaluate current literature regarding the applicability and effectiveness of the PML when implemented in AOS intervention.

Methods

<u>Search Strategy</u>
Online databases including: Google Scholar, Scholars Portal, and Gale Academic OneFile were searched using the following key terms: (Apraxia of Speech) AND (Principles of Motor Learning) AND (Treatment) OR (Intervention). The search was limited to articles published after 2005.

<u>Selection Criteria</u>
Search results yielded both AOS and Childhood Apraxia of Speech (CAS) studies. Both disorders vary in terms of onset and characteristics, therefore only AOS research was selected for the purpose of this paper.

<u>Data Collection</u>
The search yielded six articles that met the aforementioned criteria, and included five single-subject designs and one randomized clinical trial.

Results

Single-Subject Designs

Single-subject designs are appropriate for testing AOS, as this population accounts for a small percentage of acquired neurological communication disorders (Hula et al., 2008). These designs allow for systematic manipulation of variables to compare treatment effects, which is suitable for analysis of the many parameters that comprise the PML. Participants in single-subject designs serve as their own controls and are subject to selection bias, therefore it is challenging to generalize results to larger populations.

Hula, Robin, Maas, Ballard, and Schmidt (2008) conducted two single-subject, alternating treatment designs to examine the acquisition and retention of speech movements in individuals with AOS when the PML of feedback frequency and timing were altered. Despite great variability within the AOS population, selection criteria accounted for many details. The high possibility of concomitant aphasia was also addressed. Participants exhibited many differences.

Experiment 1 tested feedback frequency effects on four participants with AOS from a stroke. Methods for intervention involved two treatment phases consisting of 14-16 sessions. Procedures were described in detail and required participants to complete 30 minutes of elicited speech productions while being provided with feedback on either 60% or 100% of productions. Relatively stable baselines were achieved. Appropriate probes were administered to measure change. Outcome measures were based on examiners' perceptual judgment, and descriptions of what constituted as a correct or incorrect speech production were vague. Experiment 2 compared feedback timing effects, and involved two of the four participants from Experiment 1. This experiment followed a near-identical procedure to the previous experiment, however participants were presented with either immediate or delayed feedback (5s) following speech productions.

Data was presented in graphs and allowed for visual interpretation. Results from Experiment 1 indicated that high frequency feedback enhanced acquisition of speech skills in one participant, and low frequency feedback enhanced retention and transfer in two participants. Results from Experiment 2 indicated that immediate feedback enhanced the acquisition of speech skills in one participant, and delayed feedback enhanced retention and transfer in one participant. Authors reported that the effects of feedback delay might have been masked by a stimulus complexity effect.

Participant criterion was representative of the AOS population despite their differences. Treatment proceedings were thorough and presented in a replicable manner. Significant limitations of this study included use of subjective ratings, low stimuli functionality, and modification of probes during intervention. Due to the many limitations of this study, results are somewhat suggestive in addressing the argument of whether these PML enhance AOS intervention.

Friedman, Hancock, Schulz, and Bamdad, (2010) investigated the PML when incorporated into a modified version of the Motor Learning Guided (MLG) approach to establish automatic and accurate speech in a 29 year-old male with moderate-severe AOS from a traumatic brain injury (TBI). The implemented PML included blocked and random practice schedules, complex target complexity and delayed, low summary, knowledge of results (KR) feedback. This single-subject (ABA) design was conducted over 29 sessions, and included a baseline phase followed by two phases of intervention. Appropriate detail outlining each intervention phase was provided. Researchers designed a multidimensional scoring scale to measure outcomes. Adequate interrater and intrarater reliability was achieved, after modifications were applied to the scoring scale. Baseline was of appropriate duration, and posttest measures (3 months) were taken.

Appropriate data analysis was performed and results showed the participant's speech became more automatic and accurate as treatment progressed. Performance on MLG target items at posttest showed successful maintenance effects.

The ABA design used is appropriate for this study. The case was well described, and treatment proceedings are replicable. The multidimensional scale used to measure outcomes offers an objective approach to measuring apraxic speech. The study failed to acknowledge the lack of maintenance data reported for one treatment phase, which presents as a significant limitation. Despite this limitation, Friedman et al. (2010) provided highly suggestive evidence that the investigated PML, when incorporated into a modified version of MLG intervention, can successfully train functional speech phrases in individuals with AOS and produce long-term retention effects.

Ballard, Mass, and Robin (2007) investigated the effects of variable practice with delayed, KR feedback in treatment for voicing control in two participants with moderate AOS. Participants differed greatly in etiologies, as one participant suffered from a stroke, and the other a TBI. Treatment proceedings are presented in a detailed, replicable manner. In an effort to avoid perceptual bias, outcomes were analyzed using spectrogram data. Adequate baselines and probes were administered to measure change, maintenance, and generalization. Acceptable data points were collected from each participant pre-intervention, post-intervention, and at 3 weeks and 3 months follow up.

Interpretation of results included appropriate statistical analysis and graphs allowed for visual inspection. Sufficient interrater and intrarater reliability was reported. Analyses showed both participants made advances in trained behaviours, generalization of trained behaviours to a novel stimulus, and maintenance of effects post-treatment. Generalization to untrained stimuli of the same manner only also occurred, supporting hypotheses.

An apparent strength of this study is the use of a spectrogram to objectively measure speech and provide biofeedback. Treatment was administered in a contrived clinical setting, presenting as a weakness. Another notable limitation is that voicing data of one participant may have been masked by the fluency of their speech. Overall, the evidence that the PML of variable practice and delayed, KR feedback promote voicing control in individuals with AOS is compelling.

Wambaugh, Nessler, Cameron, and Mauszycki (2013) employed a multiple baseline, single-subject design to examine the effects of practice schedule and practice distribution in Sound Production Treatment (SPT) of four individuals with AOS and Broca's aphasia that resulted from a stroke. Despite the consistent diagnosis of Broca's aphasia, participants varied greatly in terms of time post-onset of stroke (26-232 months). Treatment phases involved four phases and were outlined in a replicable manner. Appropriate baseline measures were achieved and probes were administered throughout treatment, as well as at 1 week, 2 weeks, and 3 weeks post-intervention. Outcomes measures were appropriate. Methods of data collection were thoroughly explained, but may have been subject to experimenter bias. Adequate interrater reliability was achieved.

Data analyses were appropriate for the design at hand. Results showed successful changes in word production accuracy for all participants in each phase of treatment, with no significant differences among treatment phases, indicating massed versus distributed practice and blocked versus random practice schedules produce similar treatment effects. Significant maintenance effects were not observed.

An apparent strength of this study is that raters were blinded to treatment phases. A notable limitation is researchers held the duration of intervention sessions constant across participants. As a result, as well as the use of challenging stimuli lists, participants were unable to reach their maximum performance (i.e., 90% accuracy) before maintenance was measured. Also, differences between treatment conditions (i.e., blocked and random practice) were minimal. Due to these significant design limitations, this study presents equivocal evidence that the PML do not enhance SPT intervention for individuals with AOS.

Youmans, Youmans, and Hancock's (2011) study focused on the PML of blocked practice during acquisition, as well as random practice, and delayed and summary feedback in retention. This multiple baseline, single-subject design investigated the effects of these PML in script training, a common treatment approach for persons with aphasia, in three individuals with AOS from a stroke. All participants presented with mild anomic aphasia, yet varied in terms of AOS severity, and were administered intensive training in functional conversational scripts. Amount of treatment sessions varied by participant. Relatively stable baselines were achieved prior to treatment, and probes were administered throughout treatment, as well as 2 weeks, 2 months, 4 months and 6 months posttest. Maintenance data of one participant was not collected. Outcome measures included analysis of speaking rate, a percentage of words produced correctly, and self-rating measures.

Detailed graphs of results were provided for visual inspection. Results demonstrated a marked increase in script accuracy from baseline to treatment phases, with robust maintenance effects for two participants. Speaking rate varied greatly throughout treatment and maintenance for all participants. All participants reported increased self-confidence when speaking.

Youmans et al. (2011) incorporated functional, personally relevant scripts specific to each participant, presenting as a major strength. Treatment duration was tailored to each participant, allowing participants to demonstrate robust retention of learned speech skills. Researchers also attempted to minimize potential interaction effects that may have occurred between blocked and random practice conditions, and robust interrater reliability was demonstrated. An apparent weakness is that the clinicians appointed to administering treatment sessions across treatment phases were varied. Results from this study suggest compelling findings that the incorporation of several PML into script training enhances speech outcomes in individuals with AOS and mild anomic aphasia, and promote further investigation of script training in AOS treatment.

Randomized Clinical Trials

Randomized clinical trials are strong, quantitative study designs and consist of random allocation of participants to a specific intervention. Typically, one intervention condition acts as a control group to which other conditions can compare. This design is appropriate for the study of PML in intervention, as the outcomes of the intervention conditions can be measured and contrasted. Large sample sizes are often needed for adequate calculation of power in these designs, which is difficult to achieve in the AOS population.

Bislick, Weir, and Spencer (2012) employed a randomized group design to investigate the effects of feedback frequency on 10 individuals with AOS and mild aphasia. Participant selection criteria was stringent and well described. Each participant completed a novel speech task and a manual limb task. They were then instructed to perform the same tasks at a rate that was 2x and 3x slower than their habitual rate. Participants were divided into two groups, one group was provided with feedback after each trial and one group was provided with feedback after every five trials. Tasks were completed over two sessions. Adequate baseline measures were administered and posttest measures were taken 2-4 days after treatment. Generalization to novel stimuli was also measured. Outcome measures were vague, as criteria of incorrect versus correct speech productions were not specified.

Appropriate statistical analysis was performed, and data was presented visually in graphs for further interpretation. In the speech task, trends indicated that participants who received more frequent feedback were more accurate in the 2x slower task, and less accurate in the 3x slower task when compared to participants who received less feedback. The reverse trend was observed for the manual limb task, suggesting feedback frequency poses different effects on speech and motor learning. Trends were not replicated across all participants and no differences that were observed were significant.

An apparent strength of this study is that participants were randomly allocated to groups. This study involved several limitations. Intrarater and interrater reliability was not reported, stimuli were non-functional and were administered in a contrived setting, and participants were exposed to an insignificant amount of practice. Due to these limitations, this study provides equivocal evidence that feedback frequency effects differ between speech and limb motor learning.

Discussion

This critical review analyzed current literature regarding the effectiveness and applicability of the PML when incorporated into intervention for individuals with AOS. Limited research is available on this subject, and researchers of AOS and the PML are confronted with several limitations. Despite inherent challenges, current literature presents suggestive evidence supporting the use of various PML in AOS intervention. Of the six articles reviewed, three highlighted the benefits of PML-guided intervention for individuals with AOS in a compelling or highly suggestive manner, specifically supporting the PML of target complexity, practice schedule, practice variability, as well as feedback type, timing, and frequency. The current evidence does not explicitly state the most effective PML parameters in AOS intervention, nor are they administered in a consistent manner across studies.

Several challenges arose from the investigation of PML intervention outcomes in AOS. The amount of the investigated PML varied greatly across studies. Ballard et al. (2007) investigated the sole principle of practice variability in the retention phase only (variable practice), while Friedman et al. (2010) examined practice schedule, target complexity and all feedback principles, comparing effects of acquisition and retention phase parameters. Also, most studies examined intervention effects of several PML simultaneously, making potential interaction effects likely. Ballard et al. (2007) and Bislick et al. (2007) examined the treatment effects of one principle only. This approach presented as a strength as interaction effects of PML were limited.

PML were implemented into diverse intervention methods across studies, making intervention effects difficult to compare. For example, Wambaugh et al. (2013) investigated the PML effects on SPT, a conventional AOS treatment. Youmans et al. (2011) contrarily investigated script training, a common aphasic treatment that had not yet been applied to AOS. Also, there are few findings to guide decisions on when an individual with AOS has demonstrated acquisition of a speech skill and should advance from acquisition PML to retention PML during practice. Most PML are also broadly defined in the literature using qualitative language. Concise, quantitative definitions will make PML easier to research and implement into clinical practice.

This review evaluated five single-subject designs and one randomized clinical trial. Longitudinal data to support or refute intervention generalization and maintenance effects occurred in all analyzed studies. ABA or multiple baseline designs were most effective in demonstrating causality. Hula et al. (2008) implemented an alternating treatment design to compare the treatment effects of PML of the acquisition phase versus retention phase. The most effective treatment was difficult to determine, as carry-over effects may have resulted from this design. The randomized clinical trial performed by Bislick et al. (2012) was suitable for the question at hand, as the benefits of the PML, as stated in the literature, were mixed prior to randomizing intervention groups. This design may also incorporate larger sample sizes than single-subject designs. Going forward, alternating treatment designs present the most detrimental weaknesses when investigating the PML.

Research involving AOS presents apparent challenges that were evident within these studies. Small sample sizes are common, as AOS accounts for a mere 4% of motor speech disorders (Hula et al., 2008). Variability exists within this population, and literature regarding the characteristics of AOS is inconstant, making it difficult to identify. A hallmark feature of AOS involves inconsistent speech errors, making stable baseline measures evidently difficult to achieve. Given these factors, single-subject designs are suitable for this research. However, restricted generalizability of outcomes to this clinical population result from the aforementioned issues.

Conclusion

Current literature provides evidence that intervention guided by the PML, including practice schedule, amount, variability, and target complexity, as well as feedback type, timing and frequency, improve speech outcomes in individuals with AOS. A considerable amount of evidence yielded suggestive results pertaining to the effectiveness of the PML in AOS intervention. Further research is recommended to strengthen the evidence presented in this review.

Clinical Implications

Given that each study involved in this critical review involved small samples sizes, speech-language pathologists might cautiously implement the PML noted above in AOS intervention. The clinician should monitor intervention outcomes carefully and directly, being mindful that current evidence supports the specific PML of target complexity, practice schedule, practice variability, as well as feedback type, timing, and frequency, to enhance long-term retention of speech skills in individuals with AOS.

Future investigations are required to augment existing literature. The following recommendations should be considered in this research:

1. In the study of AOS, baseline measurements are difficult to establish due to inconsistent errors involved in this disorder. Strong empirical designs are necessary to control for this factor. Multiple baseline and ABA single-subject designs presented the strongest evidence in this review.

2. Potential interaction effects between the PML may have occurred in several of the analyzed studies. Obtaining evidence to support use of each principle as its own entity in AOS intervention will promote credibility of each principle to be used in clinical practice.

3. Future research should involve detailed procedures of each PML used in intervention, allowing principles to be defined in a quantitative manner. This will allow for further replication of procedures in literature, and promote clinical implementation.

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Appendix A: The Principles of Motor Learning

Principle of Motor Learning	***Acquisition Phase*** Principles that support short-term performance enhancement	***Retention Phase*** Principles that support long-term learning
Practice Schedule Predictability of target presentation	**Blocked** (e.g., AAA BBB)	**Random** (e.g., ABC, BCA)
Practice Distribution How a set amount of trials/sessions are practiced over time	**Massed** Intensively over a short time period	**Distribution** Spread out over a long time period
Practice Variability Amount of movement parameters (GMPs) targeted per session	**Constant** Consistent target/contexts	**Variable** Varied target/contexts
Practice Amount Amount of trials/treatment session	**Small**	**Large**
Attentional Focus	**Internal** On bodily movement	**External** On effect of bodily movement
Target Complexity Practice of parts of a movement versus a whole movement	**Simple** Easier, early acquired sounds and stimuli	**Complex** Challenging, later acquired sounds and stimuli
Feedback Type Information given after target production	**Knowledge of Performance (KP)** Target-specific feedback	**Knowledge of Results (KR)** Target accuracy feedback
Feedback Timing When feedback is provided relative to the target production	**Immediate**	**Delayed** (e.g., 5 sec)
Feedback Frequency	**High** After every trial	**Low/Summary** After some trials