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The role of motor learning in stuttering adaptation: repeated versus novel utterances in a practice-retention paradigm

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Abstract

Most individuals who stutter become more fluent during repeated oral readings of the same material. This adaptation effect may reflect motor learning associated with repeated practice of speech motor sequences. We tested this hypothesis with a paradigm that used two integrated approaches to identify the role of motor learning in stuttering adaptation: to distinguish practice effects from situation effects, the texts contained both repeated and novel sentences; to differentiate learning effects from temporary performance effects, stuttering frequency was determined for both the initial adaptation readings and retention tests after 2 and 24 hours. Average group data for 7 stuttering individuals who showed adaptation indicate that (a) both repeated and novel sentences resulted in decreased stuttering frequency across five readings in the initial session, but the decrease was larger for repeated than for novel sentences; (b) after 2 hours, stuttering frequency for both types of sentences was again similar, but with additional readings the repeated sentences once again showed larger improvements in fluency; (c) after 24 hours, prior fluency improvements for the novel sentences had dissipated whereas retention was observed for the repeated sentences. These findings–supporting the hypothesis that motor learning plays a role in stuttering adaptation–were representative for most, but not all, individual subjects. Subjects whose data did not follow the group trend and showed comparable retention for repeated and novel sentences may adapt primarily on the basis of non-motor mechanisms. Alternatively, those subjects may in fact show more substantial generalization of motor learning effects to previously unpracticed movement sequences.

Educational objectives—After reading this article, the reader will be able to: (1) summarize previous research on stuttering adaptation; (2) define motor learning and describe its essential characteristics; and (3) discuss why the results from this and previous studies suggest that stuttering adaptation may be a result of motor learning.

Keywords

stuttering; adaptation; motor learning; practice; retention

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1. Introduction

It is well documented that many people who stutter show a substantial decrease in stuttering frequency during repeated readings of the same material–a phenomenon known as the adaptation effect (for a review, see Bloodstein and Bernstein Ratner, 2008). Typically, the average decrease in frequency of stuttering moments for a group of individuals who stutter is approximately 50% across five repeated readings of a given text (Johnson, Brown, Curtis, Edney, and Keaster, 1967). Although many authors have recognized that this considerable improvement in speech fluency during an adaptation task may hold important information that could advance our understanding of the mechanisms underlying stuttering (Johnson et al., 1967; Prins and Hubbard, 1990; Quarrington, 1959; Zimmermann and Hanley, 1983), more than 80 years after the first published report by Johnson and Knott (1937) there is still no generally agreed upon explanation for the effect. Over the years, a wide variety of hypotheses have been proposed. For example, it has been suggested that the decrease in stuttering frequency across repeated readings may result from anxiety deconfirmation (Johnson et al., 1967; Sheehan, 1958), experimental extinction (Jones, 1955; Wischner, 1950), reactive inhibition (Brutten and Shoemaker, 1967; Gray and Brutten, 1965), decreased propositionality of the reading material (Eisenson, 1958, 1975), or motor rehearsal (Frank and Bloodstein, 1971; Wingate, 1986a,b).

More recently, it has been suggested that the adaptation effect may be a result of motor learning (Balasubramanian, Max, Van Borsel, Rayca, and Richardson, 2003; Caruso and Max, 1997; Max, 2004; Max, Caruso, and Vandevenne, 1997; Max and Caruso, 1998). Unlike previous hypotheses based on the general concept of motor rehearsal (which can lead to both temporary and relatively long-term changes), the hypothesis originally proposed by Max et al. (1997) focuses more directly on the learning processes involved in motor skill improvements. Motor learning is generally accepted to involve "a relatively permanent change in behavior that is a result of practice or experience, and not a result of maturation, motivational, or training factors [whereas] motor performance, as distinct from motor learning, is the observable behavior exhibited when one performs a motor task" (Sage, 1984, p. 16). Thus, the motor learning hypothesis of stuttering adaptation uses a well-developed theoretical framework from the nonspeech literature that makes it possible to formulate empirically testable hypotheses regarding (a) the influence of several independent variables (e.g., practice schedule, reading material) on the stuttering adaptation effect, and (b) short- and long-term behavioral, kinematic, and neural changes associated with motor skill improvements in individuals who stutter.

Previous work on the adaptation effect yielded behavioral data (stuttering frequency counts as well as acoustic measures) that were consistent with a motor learning interpretation, but the studies were not specifically designed as empirical tests of that hypothesis (Max et al., 1997; Max and Caruso, 1998). Therefore, the purpose of the present study was to investigate more directly the hypothesis that stuttering adaptation may reflect speech motor improvements resulting from motor learning. This objective was accomplished with an adaptation paradigm that integrated two parallel approaches to identifying the presence or absence of motor learning effects. As a first approach, the reading passages contained both repeated sentences that occurred in each of the five readings within a test session and interspersed novel sentences that occurred in only one single reading per test session. In each reading, stuttering frequency was then determined separately for the repeated versus novel utterances. A similar approach had been previously used by Golub (1955) for the reading of word lists (demonstrating a decrease in stuttering frequency only for words that were repeated in each list and not for words that were novel in each list) but, to the best of our knowledge, has not been used with sentence-level utterances in a meaningful passage. As a second approach to isolating potential motor learning effects, the present work relied on the well-established agreement in the motor learning literature that true learning effects can be differentiated from temporary performance effects by measuring subjects performance during a retention test after sufficient time has passed for the temporary effects to disappear (Sage, 1984; Schmidt, 1988, 1991). Here, we examined retention of any improvements in speech fluency for both the repeated and the novel utterances in additional sessions that took place 2 hours and 24 hours after the initial session.

2. Materials and methods

2.1. Subjects

The subjects for this study were 8 male and 2 female individuals who stutter, ranging in age from 16 to 61 years (mean age = 33.6 years). Subjects were recruited from the laboratory's participant pool on the basis of their potential ability to participate in three separate sessions over two days. Pertinent information about each individual subject is included in Table 1. All subjects reported that the onset of their stuttering occurred between 2 and 7 years of age. Based on the Stuttering Severity Instrument 3rd Edition (SSI-3; Riley, 1994), the disorder was classified as mild in three cases, moderate in three cases, severe in two cases, and very severe in two cases. Eight subjects were native speakers of American English; two subjects (S2 and S10) were non-native speakers who had been using English as their primary language for several years. Subjects reported that they had no current or former communication or neurological disorders other than stuttering, except for one subject (S8) who reported that, during childhood, he had been considered to have a nonverbal learning disability.

2.2. Procedure

Subjects were tested individually in a paradigm that involved three separate sessions with five oral readings per session. No breaks were given between successive readings within a session. In Session I, subjects read five 400-word texts with a similar and neutral content from a computer monitor. Half the sentences (consisting of 200 words total) remained constant from reading to reading whereas the other sentences (also consisting of 200 words total) were replaced in each reading. Specifically, each text consisted of alternating repeated (i.e., identical across the five readings) and novel (i.e., different across the five readings) sentences. The texts were created such that measures of readability (Flesch, 1951) and stuttering probability (Browns word weights–Brown, 1945) were similar for all six sets of sentences (i.e., one set constituting the repeated sentences for each of the five successive readings and five sets constituting the novel sentences for those same readings). Detailed information regarding the readability and stuttering probability indices for the six sets of sentences is provided in Table 2. Taking into account that all sets of sentences were equated for readability as well as stuttering probability, the passages created by interspersing repeated and novel sentences were presented to all subjects in the same order.

Subjects then left the laboratory, and returned two hours later for Session II. During this first retention test, subjects re-read the same five texts under the same conditions as in Session I. Overall environment, presentation of the passages, verbal instructions, and the number of researchers present in the room (two for most subjects, one for others) were controlled and kept constant across the sessions. Subjects then left the laboratory again, and returned twenty-four hours after Session I to complete Session III. During this second retention test, they once again read the same five texts in the same order under the same controlled conditions.

Throughout all three sessions, each subject's speech was recorded with a microphone (Shure SM58) and audiotape deck (JVC TD-W354BK or TAS-CAM 202MKIV) for off-line stuttering frequency analysis (i.e., measures of percent stuttered syllables) by an ASHA-certified speech-language pathologist with extensive experience in the assessment of stuttering. Due to human error, no recording was made of subject S8's readings in Session II, but recordings of all other 145 readings (9 subjects with 15 readings and subject S8 with 10 readings) were available for analysis. For the purpose of this study, moments of stuttering were defined as part-word repetitions, monosyllabic whole-word repetitions, audible and inaudible sound prolongations, or broken words (Conture, 1990).

2.3. Measurement reliability

To verify reliability of the stuttering frequency measures, a second judge identified and counted the number of stuttering moments in a subset of the original readings. This subset consisted of ten 400-word readings (i.e., 4000 words total), compiled by randomly selecting one reading from each of the 10 subjects' recordings. The second judge rated all reading samples while blind with regard to subject information, the session number (I, II, III) from which the particular reading was selected, the number of the reading (1 through 5) within the session, and the primary judge's stuttering frequency count for the reading. For each reading individually, inter-judge reliability was then calculated using both an overall stuttering frequency Agreement Index (Sander, 1961) and Kappa (Cohen, 1960). Sander's index is widely used in the stuttering literature whereas Kappa is a measure that provides more specific information regarding observer agreement for stuttering event judgments because it indicates the proportion of syllable-by-syllable agreement after removal of agreement that can be expected to occur by chance (Cohen, 1960, 1968; Lewis, 1994). For the 10 reading samples included in the reliability analysis, the mean Sander's index was .94 (range = .87–1.00) and the mean Kappa index was .89 (range = .74–.97).

2.4. Validity of the paradigm and statistical analyses

Given that the aim of this work was to examine whether or not motor learning is likely to be a contributing factor when stuttering frequency decreases across repeated readings, individual subject data were first inspected to identify those subjects who showed such an adaptation effect when repeatedly reading the same material. For this purpose, we operationally defined adaptation as a decrease of more than three stuttering moments when comparing the averaged stuttering frequency for the repeated sentences in the last two readings of Session I with the averaged stuttering frequency for the repeated sentences in the first two readings of Session I. Using this criterion, 8 of the 10 subjects did adapt. This number confirms the validity of our operational definition given that it is consistent with previous literature reporting that 70% (Newman, 1963) to 85% (Gray, 1965) of individuals who stutter show an adaptation effect. Moreover, the decrease in the adapting subjects' mean stuttering frequency across the repeated sentences in Session I was 52.39% of the original stuttering frequency in Reading 1 (i.e., $\frac{Reading1-Reading5}{Reading1}$) and this observation is also highly consistent with previous literature on the adaptation effect (Bloodstein and Bernstein Ratner, 2008). In addition to providing support for our specific operational definition of adaptation, both these observations also confirm the validity of the overall approach by demonstrating that in this paradigm in which novel sentences are interspersed among repeated sentences, both the percentage of subjects who adapt on the repeated sentences and the size of the adaptation effect for those sentences are similar to those seen in studies in which an entire passage is repeated.

Using percent stuttered syllables as the dependent variable, statistical comparisons (a) between repeated and novel sentences within the same session or (b) between sessions for the same set of sentences (either repeated or novel) were completed with *a priori* paired t tests for which α was set at .05. As a measure of effect size, Cohen's d was calculated (Cohen, 1988). In accordance with procedures recommended to avoid inflated effect sizes in the case of repeated measures designs, *d* values were calculated using the actual standard deviations from each condition rather than the *t* value obtained with the paired *t* tests (Dunlop, Cortina, Vaslow, and Burke, 1996). Interpretation of *d* effect size values is based on the general rule that .20 reflects a small effect, .50 a medium effect, and .80 a large effect (Kirk, 1995).

Subjects S7 and S9 did not meet the aforementioned criterion for the operational definition of adaptation. Combined with the fact that no Session II data were available (see above) for subject S8 who did meet the adaptation criterion, group mean data for this work are based on 7 individuals. However, group results are described, illustrated, and interpreted together with the data obtained from all individual subjects.

3. Results

Figure 1 shows group mean data for percent stuttered syllables across the five readings in each of the three sessions. A first important observation is that stuttering frequency was very similar for the repeated and novel portions of the text during Reading 1 in Session I when both portions were seen and read for the first time ($t(6) = 1.145$, $p = .296$, $d = .11$). A prerequisite for meaningful interpretation of all data from the study, this finding confirms that the repeated and novel portions of the text elicited similar amounts of stuttering prior to practice. Across the five readings in Session I, the mean stuttering frequency for repeated sentences then showed a decrease of 52.39% whereas the mean stuttering frequency for novel sentences showed a decrease of 35.93%. This difference between the repeated and novel sentences in extent of adaptation during Session I was statistically significant and associated with a large effect size ($t(6) = 2.498$, $p = .047$, $d = .87$). As a result, by Reading 5 at the end of Session I, subjects were statistically significantly more fluent when reading repeated sentences than when reading novel sentences ($t(6) = -2.816$, $p = .030$, $d = .39$).

Applying the same descriptive and statistical analyses to the retention test in Session II, it was found that stuttering frequency during the first reading after two hours was again similar for the repeated and novel portions of the text ($t(6) = -0.418$, $p = .690$, $d = .06$). It can be seen in Figure 1, however, that both the repeated and the novel sentences showed partial retention of the fluency improvements achieved during Session I. Expressed as a proportional reduction in mean stuttering frequency relative to Reading 1 of Session I, *retention of fluency* in Reading 1 of Session II was 30.49% for the repeated sentences and 22.65% for the novel sentences. Although with our sample size of 7 adapting subjects these decreases in stuttering frequency from Reading 1 in Session I to Reading 1 in Session II were not statistically significant (repeated sentences: $t(6) = 1.586$, $p = .164$; novel sentences: $t(6) = 1.620$, $p = .156$), the associated *d* values indicated a medium effect for the repeated sentences ($d = .57$) and a small effect for the the novel sentences ($d = .40$).

As another way of examining the amount of retention, we calculated what percentage of the fluency improvement during adaptation in Session I was retained at the time of the first reading of Session II. In other words, we asked how much of the adaptation effect was maintained two hours later by expressing the decrease in mean stuttering frequency from Reading 1 in Session I to Reading 1 in Session II as a percentage of the adaption-related decrease in mean stuttering frequency from Reading 1 in Session I to Reading 5 in Session I. For the repeated and novel sentences, this *retention of adaptation* was 58.21% and 63.04%, respectively.

Across the five readings in Session II, mean stuttering frequency decreased by 36.98% for the repeated sentences and by 15.28% for the novel sentences. Despite the fact that a test based on each subject's amount of adaptation for repeated versus novel sentences during this session was not statistically significant ($t(6) = -.289$, $p = .782$, $d = .05$), by Reading 5 at the end of the session stuttering frequency was again statistically significantly lower for the repeated sentences than for the novel sentences ($t(6) = -2.477$, $p = .048$, $d = .79$).

This difference between the two sets of sentences was maintained until the second retention session on the next day: at that time, the repeated sentences were still produced more fluently than the novel sentences ($t(6) = -2.950$, $p = .026$, $d = .24$). It is clear from Figure 1 that, at the beginning of Session III, the prior fluency improvement for the novel sentences had mostly dissipated, with the indices for *retention of fluency* and *retention of adaptation* relative to Session I being 4.36% and 12.14%, respectively. For the repeated sentences, on the other hand, a considerable proportion of the prior fluency improvement was retained, resulting in *retention of fluency* and *retention of adaptation* indices of 23.33% and 44.54%, respectively. Consequently, a statistically significant reduction in stuttering frequency during Reading 1 in Session III as compared with Reading 1 in Session I was observed only for the repeated sentences ($t(6) = 2.942$, $p = .026$, $d = .40$) and not for the novel sentences ($t(6) = .539$, $p = .610$, $d = .07$).

The panels in Figure 2 show the data from each individual subject (note that subjects S7, S8, and S9 were not included in the group mean data for reasons clarified above). Of the 8 adapting subjects, 5 (S1, S2, S3, S6, S8) show a pattern that can be considered similar to the group mean data in that (a) their stuttering frequency was lower for the repeated sentences than for the novel sentences for most of the readings across Session II and/or Session III, and (b) their stuttering frequency was lower for the repeated sentences than for the novel sentences at the very beginning of the 24-hour retention test (Reading 11 in each panel of Figure 2). However, it is also clear that this pattern is not observed for all subjects. S5 showed a very small advantage for repeated sentences only in the last three readings and S4 and S10 essentially showed similar fluency gains for repeated and novel sentences throughout Sessions II and III.

4. Discussion

In this study, 10 individuals who stutter read out loud five passages that consisted of alternating repeated sentences (i.e., sentences that were re-used in each passage) and novel sentences (i.e., sentences that were new in each passage). The oral readings of the five passages were completed three times: in an initial adaptation session, in a first retention session after 2 hours, and in a second retention session after 24 hours. For this experimental paradigm, the motor learning hypothesis of stuttering adaptation (Max et al., 1997; Caruso and Max, 1997; Max and Caruso, 1998) suggested the following two predictions: (a) in the initial session, more adaptation should occur for utterances that are repeated in each reading than for utterances that are novel in each reading, and (b) across the three sessions, retention should occur only for the repeated utterances and not for the novel utterances.

Initial inspection of the data revealed that, consistent with previous literature on stuttering (Gray, 1965; Newman, 1963), 8 of the 10 subjects showed an adaptation effect for the repeated sentences in the first session. Statistical analyses completed on the data from 7 adapting subjects (one adapting subject was not included in the analyses due to missing Session II data) showed that the repeated and novel sentences elicited similar amounts of stuttering in Reading 1 of Session 1 when both sets of sentences were read for the first time. Across five readings, however, more adaptation took place for the repeated sentences than for the novel sentences, and, consequently, by the end of the adaptation session, stuttering frequency was lower for the repeated sentences than for the novel sentences. Thus, a first conclusion that can be drawn from this work is that, consistent with *practice*-based explanations of stuttering adaptation, fluency improvements are greater when utterances are produced repeatedly than when new utterances are produced in the exact same situation.

Nevertheless, the novel sentences did show a decrease in stuttering frequency during Session I, despite the fact that those sentences were not repeated. As mentioned, this decrease was more limited than that observed for the repeated sentences, but it is clear that fluency improved across the novel readings. Thus, a second conclusion is that producing the same utterances over and over again is not always necessary to achieve stuttering reductions over time. In our particular paradigm, the improvements seen for novel sentences may have occurred due to the previously suggested possibility that subjects adapt to the situation (Van Riper and Hull, 1955), or there may have been some form of carry-over of the fluency improvements experienced on the repeated sentences, perhaps analogous to transfer (i.e., beneficial generalization) from practiced to unpracticed movements in the context of motor learning (Sage, 1984; Schmidt, 1988, 1991).

A third conclusion follows from the retention data and strongly supports the motor learning hypothesis of stuttering adaptation. In the first retention test, only 2 hours after the initial adaptation session, relatively strong retention of the previous fluency gains was observed for both the repeated and the novel sentences (the quantitative indices for *retention of adaptation* were 58.21% and 63.04%, respectively). Thus, over this short time period, fluency improvements were partially retained for both sets of sentences. After an additional 22 hours had passed, however, the fluency improvement previously observed for the novel sentences had washed out almost completely whereas relatively strong *retention of adaptation* (44.54%) continued to be present for the repeated sentences. In other words, the initial retention period of 2 hours was too short to result in a loss of the improvement for the novel sentences, but the more temporary and more short-term nature of the fluency gains for those utterances was unambiguously confirmed by allowing an additional 22 hours to pass. Indeed, when subjects were tested again the next day, the differential effect of time on the retention of fluency improvements for the repeated versus novel sentences was very clear: consolidation of the achieved fluency gains had occurred exclusively for the set of sentences that had been produced repeatedly. This important finding provides compelling evidence in favor of a motor learning interpretation of the improvements that are consistently observed for repeated (i.e., practiced) utterances in a typical adaptation paradigm and is not consistent with claims that, instead, subjects simply adapt to the situation.

Besides the finding of differential effects on retention of adaptation for practiced versus unpracticed sentences, the actual amount of retention observed in these productions of repeated sentences is noteworthy. Previous work has often resulted in the claim that the fluency gains associated with adaptation disappear (sometimes referred to as spontaneous recovery of the stuttering) within a few hours (Bloodstein and Bernstein Ratner, 2008). Closer inspection of those previous studies shows that, typically, the conclusion was reached on the basis of a statistically significant increase in stuttering frequency from the last reading of the adaptation task to the first reading of the retention test. However, an appropriate and meaningful index of retention should not determine simply whether there was an increase in stuttering frequency relative to the last practice reading after a certain amount of time has passed, but, rather, whether a proportion of the achieved improvement relative to the *initial* practice reading (i.e., baseline level) is still maintained at that time. This proportion is the quantity expressed by our *retention of adaptation* index.

Hence, for comparison purposes, we applied the same index to three older studies for which the relevant data were available in the published papers. Our calculations of *retention of adaptation* yielded the following results for those previous studies: 78% 1 hour after three repeated readings and 87% 1 hour after ten repeated readings in Frick (1955); 54% .5 hours after an average of 10 repeated readings and 45% 1.5 hours after an average of 10 repeated readings in Jamison (1955); and 48% 24 hours after five repeated readings in Jones (1955). Thus, combined with our new data from the study reported here, it is now clear that a large proportion of the improvements in speech fluency during adaptation readings is maintained over periods ranging from 1 to 24 hours. In light of the accepted use of retention paradigms to distinguish temporary changes in performance from true learning effects (Schmidt, 1988, 1991), we interpret these previous studies as additional evidence in support of a motor learning interpretation of stuttering adaptation.

Despite the compelling nature of these findings based on group average data, it is important to keep in mind that the individual subject data (which we considered in Figure 2) are not only more noisy but also show that some adapting subjects (3 out of 8) experienced no fluency benefit of repeated versus novel sentences at the beginning of the second retention test. For two of these subjects (S4 and S5), the prior fluency gains were mostly lost after 24 hours for both sets of sentences (i.e., no consolidation took place for the repeated sentences). The third subject (S10) showed a very different pattern: this subject did experience a benefit of repeated versus novel sentences in the initial adaptation session, but subsequent fluency gains for both sets of sentences were equally retained until the second retention session. Although it is possible that there is a subgroup of stuttering individuals who adapt primarily on the basis of mechanisms not related to motor learning, an alternative interpretation is that some subjects (such as, for example, S10) do in fact adapt on the basis of motor learning but show greater generalization of those learning effects to previously unpracticed movement sequences. This hypothesis cannot be addressed with the current paradigm and the data reported here, but warrants further investigation in future studies.

Some additional potential limitations of the paradigm should also be acknowledged. First, the 5 sets of novel sentences (used in Readings 1–5) were re-used in the two retention sessions. This provided the advantage of allowing true retention tests after 2 and 24 hours (i.e., re-testing subjects on the same task that had been previously practiced), but an unavoidable consequence is that those sentences were not truly novel throughout the entire paradigm because each set was read 3 times in total (versus 15 times for the repeated sentences). However, any concerns about a possible influence of producing the same novel sentences in the three sessions on our attempt to dissociate fluency levels for practiced versus unpracticed utterances are mitigated by previous data showing that three repeated readings of a passage result in only a minimal amount of adaptation (approximately 10%) if the readings are separated by 30 minutes and in no adaptation at all if the readings are separated by 24 hours (Shulman, 1955). Second, for the sake of continuity of the reading material and to minimize the chances of subjects becoming aware of the alternating sequence of repeated and novel sentences, some individual words from the repeated sentences also occurred in the novel sentences. In other words, although the sets of novel sentences did not contain any sentences that were also produced in another reading within the same session, they did contain some individual words that were repeated in the same reading as well as other readings within the same session. Admittedly, this may have had an influence on the stuttering frequency measures for the novel sentences. We believe, however, that the decision to include these words for the purpose of enhancing the consistency of the content across sentences was an acceptable trade-off given that, in interviews after their third session, all subjects indicated that they had not noticed that some sentences in the various passages were repeated whereas other sentences were not repeated.

In conclusion, average group data for stuttering individuals who showed adaptation indicate that (a) both repeated and novel sentences resulted in decreased stuttering frequency across five readings in the initial session; (b) this decrease was larger for repeated than for novel sentences; (c) 2 hours after the initial session, partial retention of the fluency gains was seen for both types of sentences; (d) with additional readings, the repeated sentences once again showed larger improvements in fluency; and (e) 24 hours after the initial session, fluency improvements for the novel sentences had almost completely dissipated whereas partial retention was still observed for the repeated sentences. These group findings–supporting the hypothesis that motor learning plays a role in stuttering adaptation–were representative for most, but not all, individual subjects. In addition to supporting the hypothesis under investigation, this work validates for sentence-level utterances a paradigm that had previously been used only with isolated words (Golub, 1955), and it provides a description of stuttering individuals' behavioral responses during adaptation and retention tests. As such, the work provides ample motivation for future studies to examine changes in acoustic, kinematic, electromyographic, and neural recordings in the same and similar experimental paradigms. For example, it may be feasible to use sparse sampling functional magnetic resonance imaging (fMRI) with the aim of testing hypotheses regarding differential neural activation patterns associated with the production of repeated versus novel sentences during adaptation and retention sessions. Studies with the potential to uncover sensorimotor mechanisms underlying the learning processes that take place when stuttering individuals improve–without instruction and apparently effortlessly–from their typical dysfluency levels to the adapted and retained levels would provide important insights into the neural basis of the disorder as well as suggestions for the application of motor learning principles in clinical management approaches.

CONTINUING EDUCATION

QUESTIONS

1. The adaptation effect of stuttering refers to:
    - **a.** An increase in stuttering frequency during repeated readings of the same text
    - **b.** A decrease in stuttering frequency during repeated readings of the same text
    - **c.** A decrease in stuttering frequency during natural conversation
    - **d.** A decrease in frustration during a prolonged period of continuous stuttering
    - **e.** A decrease in stuttering frequency during readings of different passages
2. Which of the following has not previously been used to explain the adaptation effect of stuttering?
    - **a.** Sensory adaptation in the auditory pathways
    - **b.** Experimental extinction
    - **c.** Decreased propositionality of the reading material
    - **d.** Reactive inhibition
    - **e.** Anxiety deconfirmation
3. Motor learning can be defined as:
    - **a.** An improvement in motor skill as the result of maturation
    - **b.** Improvements in motor performance in the absence of practice
    - **c.** A temporary change in behavior due to motivational factors
    - **d.** Any observable changes in behavior during performance of a motor task

   - **e.** A relatively permanent change in behavior resulting from practice

4. The experimental methods used in this paper to examine motor learning in stuttering adaptation involved:
   - **a.** Stuttering and nonstuttering subjects repeatedly read selected passages
   - **b.** One group of stuttering subjects read repeated sentences while another group of stuttering subjects read novel sentences
   - **c.** Stuttering subjects read passages consisting of alternating repeated and novel sentences
   - **d.** Stuttering subjects practiced repeated and novel speech utterances as well as repeated and novel nonspeech movements
   - **e.** After each reading of a passage, stuttering subjects were reinforced for fluency improvements

5. A role for motor learning in stuttering adaptation is most strongly supported by which of the following results?
   - **a.** For both repeated and novel sentences, stuttering frequency significantly decreased within the first session
   - **b.** Fluency improvements during the first session were maintained two hours later
   - **c.** In the final reading of the experiment, stuttering frequency was lower for repeated sentences than for novel sentences
   - **d.** After 24 hours, retention was still observed for repeated sentences but not for novel sentences
   - **e.** As in previous studies, adaptation was approximately 50% and occurred in approximately 80% of subjects

ANSWERS

1. b
2. a
3. e
4. c
5. d

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Biographies

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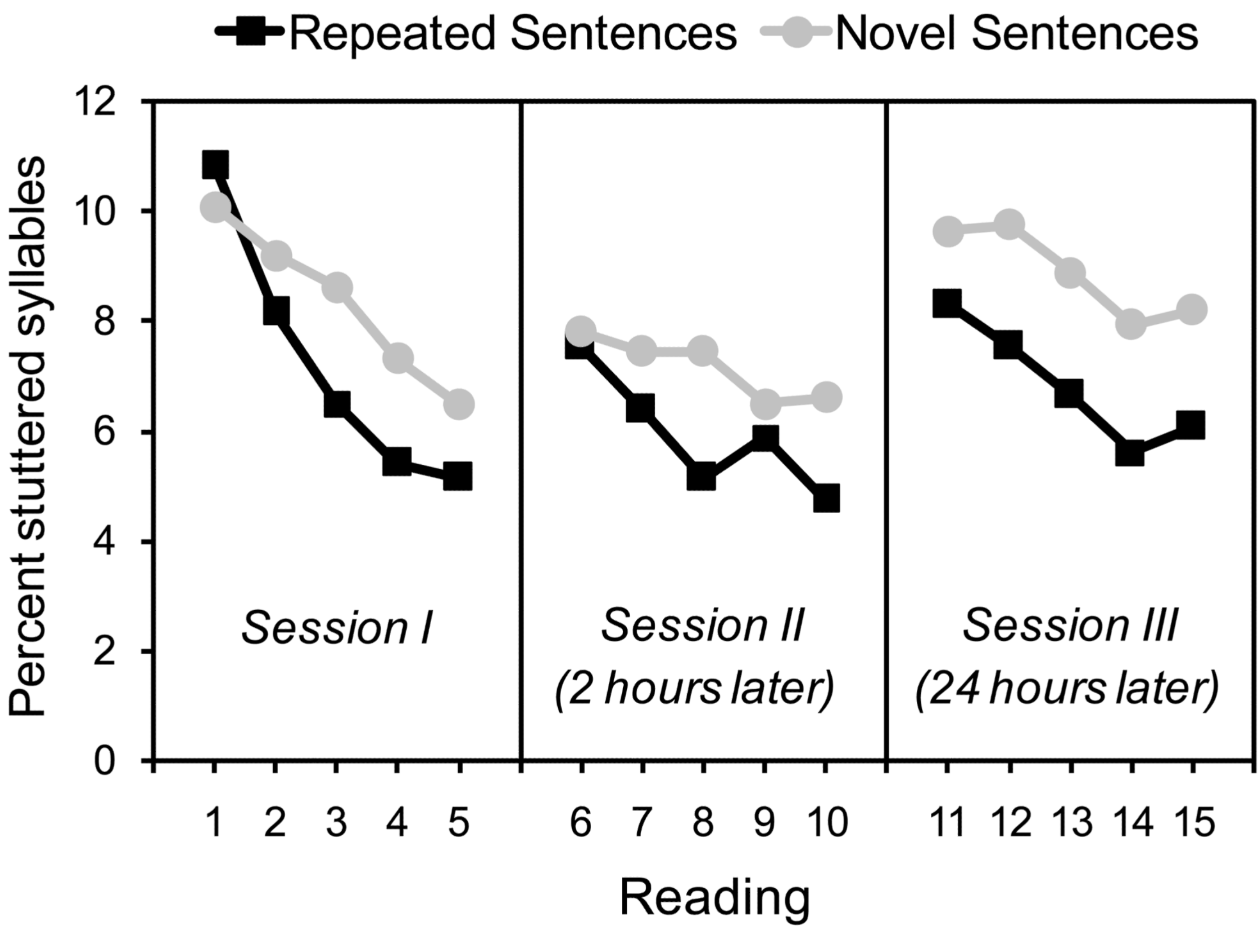

Figure 1.
Group average data for percent stuttered syllables during oral reading of sentences that were repeated versus novel across 5 readings in each of three sessions. Session II and Session III were retention tests that were completed 2 and 24 hours, respectively, after the initial readings in Session I.

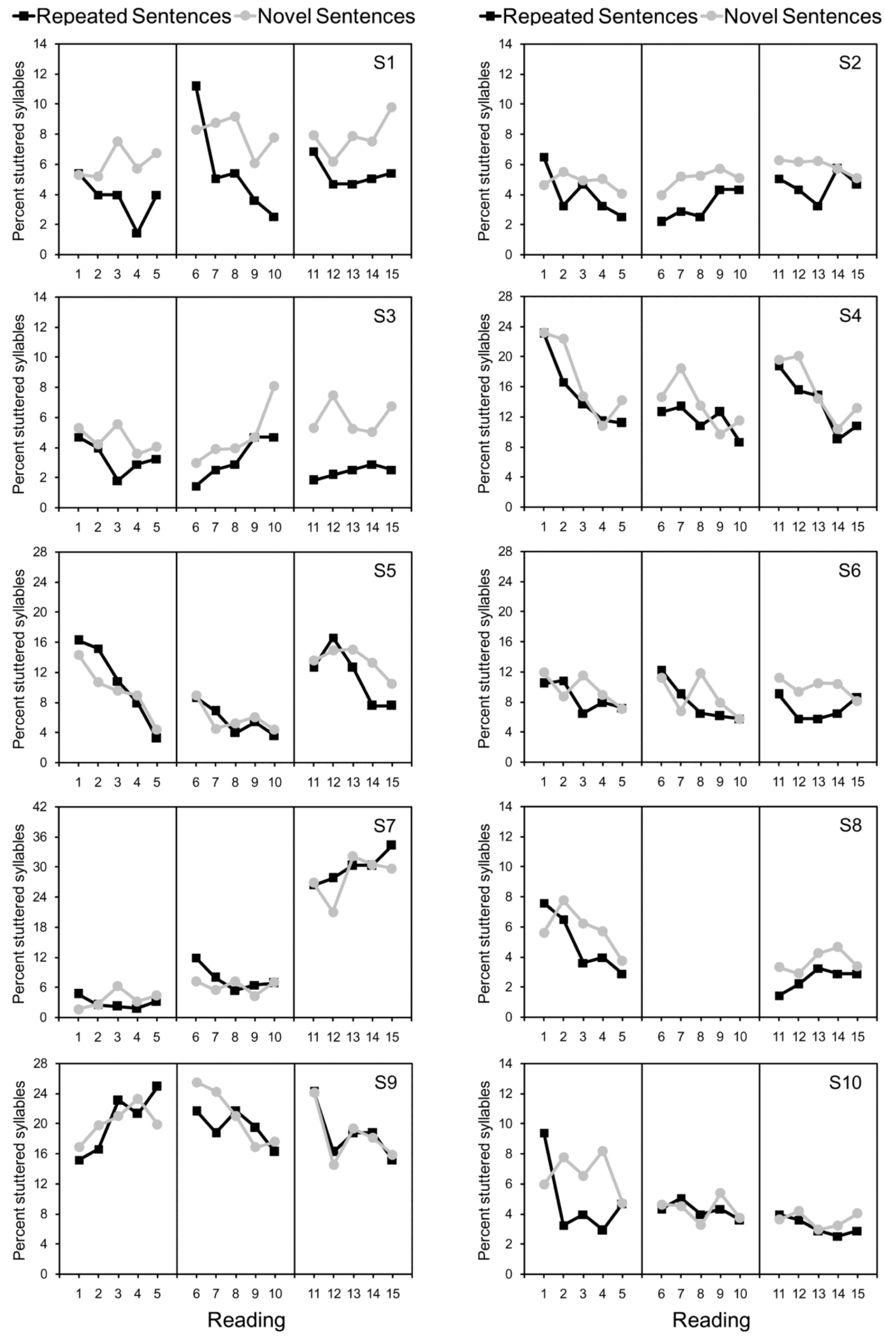

Figure 2.
Individual subject data for percent stuttered syllables during oral reading of sentences that were repeated versus novel across 5 readings in each of three sessions. Readings 1–5 were completed in Session I, 6–10 in Session II, and 11–15 in Session III. Session II and Session III were retention tests 2 and 24 hours, respectively, after the initial readings in Session I.

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Table 1

Individual subject information with regard to age, gender, overall score on the Stuttering Severity Instrument 3rd edition (SSI-3; Riley, 1994), corresponding stuttering severity classification according to the SSI-3, time of most recent treatment, native language (L1; for non-native speakers, the number in parentheses indicates the number of years lived in the United States prior to participation in this study), and self-reported communication or neurological disorders other than stuttering (n.l.d. = this subject reported a "suspected *n*onverbal *l*earning *d*isability during childhood").

Subject	Age	Gender	SSI-3	Severity	Treatment	L1	Other disorder
S1	22	male	19	mild	10 years prior	English	none
S2	29	male	36	severe	7 years prior	Urdu (5)	none
S3	61	male	27	moderate	21 years prior	English	none
S4	43	male	40	very severe	16 years prior	English	none
S5	48	female	38	very severe	23 years prior	English	none
S6	16	female	23	mild	enrolled	English	none
S7	21	male	36	severe	4 years prior	English	none
S8	19	male	27	moderate	1 year prior	English	n.l.d.
S9	48	male	18	mild	30 years prior	English	none
S10	29	male	28	moderate	3 years prior	Mandarin (20)	none

Table 2

Indices of readability (Flesch, 1951) and stuttering probability (Browns word weights; Brown, 1945) for six sets of sentences read out loud by the subjects. The *repeated* set occurred in each of the five successive readings within a test session, its sentences each time alternating with those from a *novel* set that occurred in only one reading within the test session.

Reading material	Number of words	Number of syllables	Readability index	Average word weight
repeated set	200	277	74.053	1.876
novel set 1	200	302	63.478	1.929
novel set 2	200	309	60.517	1.910
novel set 3	200	305	62.209	1.988
novel set 4	200	279	73.207	1.900
novel set 5	200	296	66.016	1.837