Research Paper: The Effect of Knowledge of Result Feedback Timing on Speech Motor Learning in Healthy Adults

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ABSTRACT

Objectives: The current study mainly aimed at studying the effect of Knowledge of Result (KR) feedback timing and result-estimation opportunity before receiving delayed KR on learning a new speech motor skill in monolingual healthy adults.

Methods: Thirty-nine Persian healthy adults were randomly divided into three groups. Each group received immediate KR, delayed KR (after eight seconds), or delayed KR (after eight seconds) with self-estimation of the result in the delay interval. All three groups received verbal KR feedback. Participants were trained to produce a French phoneme (/ın/) in the context of words in four training sessions. The correct production of the target phoneme was judged by a bilingual Persian-French examiner holding an academic degree in French language teaching. Later, a transfer test and two retention tests were administered. The two retention tests were administered one day and two weeks after the last training session respectively.

Results: The effect of feedback timing on motor performance and motor learning was examined by repeated-measures ANOVA. Performance in both acquisition and retention phases was significantly different between groups (P=0.04 for both phases). One-way ANOVA was used to investigate the transfer of learning (P=0.001). Tukey test results indicated that the groups 1 and 2 were different in both acquisition and retention phases and all three groups were different in transfer test.

Discussion: The results showed that the immediate KR is beneficial for the acquisition phase, and delayed KR is more beneficial for the retention and transfer tests compared with immediate KR.

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Highlights

- Gradually-reducing feedback does not degrade the retention of motor learning.
- Gradually-reducing and high-frequency feedback have almost similar results.
- Immediate feedback may increase the acquisition rate.
- Delayed feedback leads to better performance in retention and transfer tests.

Plain Language Summary

Providing feedback by other persons or devices can affect the learning (e.g., motor learning). The feedback can be during a task, immediately after the task, or after the task (delayed feedback). In this study, we investigate the effect of the time of external feedback on one of the motor aspects of speech, i.e., learning to produce a new sound. We used verbal feedback on the participant's trials. To investigate the impact of the time of the feedback, the participants categorized into three groups: immediate feedback, 8-second delay feedback, and 8-second delay feedback but as a self-rated interval. We considered three phases for learning: the acquisition (learn to produce the target sound in the single words), the retention (the maintenance of the ability to produce the sound after a certain time), and the transfer phase (the ability to produce target sound in non-trained words). Our results show that immediate feedback leads to better performance at early learning, but the delayed feedback is much better for retention learning and generalization of learning to non-trained motor tasks.

1. Introduction

Movement and acquiring motor skills is a fundamental requirement in human life. Human curiosity for better understanding of the fundamental processes of motor control led to an increasing number of studies in various disciplines, including rehabilitation fields. Discussion in the field of motor learning requires a functional definition of motor learning. Motor learning is a collection of intrinsic processing as a result of practice, and causes relatively stable changes in the person's ability in movement [1, 2].

During the last decades, researchers tried to determine the optimal conditions for optimizing motor learning and focusing on motor learning through changes in the structure and the amount of practice and feedback. The results of these studies in the limb motor learning, known as the principles of motor learning, describe the optimal conditions for motor learning [3]. Speech is a precise, fast and complex motor skill performed by participation and coordination of a number of muscles from various articulators. In recent years, some researchers focus on speech motor learning to determine the effects of various variables (e.g. feedback) on speech motor learning/relearning [4-6].

Studies focusing on speech motor learning tried to answer whether the principles of motor learning affect the speech motor control system in a similar way to the limbs motor control system [7]. One of the most important variables affecting the learning of motor skill is feedback [4, 8]. Feedback is the second most important variable affecting the acquisition of new motor skills [9]. Feedbacks are of two kinds; intrinsic feedback, which includes information provided by internal sources during or after the movement, and extrinsic feedback, which provides information by an external source [10, 11]. Extrinsic feedback can provide information about how the movement is performed and which motor patterns are used for doing it; this is called Knowledge of Performance (KP) feedback. Extrinsic feedback can also provide information about the result of the motor action and is called the Knowledge of Result (KR) feedback [4, 11].

Several variables related to extrinsic feedback including the frequency and the timing of the feedback are of the researchers' interests. Feedback can be presented immediately after the movement or with a delay [4]. Theoretically, the delay interval before receiving the feedback by providing the opportunity for loss of the memory tracking helps in forgetting the motor memory. Therefore, it seems that prolongation of the time between movement and feedback can degrade learning [12]. Salmon et al. showed that the delay interval before receiving feedback has no negative effects on learning, and even it can be benefitial in this regard in some cases [13, 14].

Swinnen et al. suggested that interfering in the process of other types of information, such as response-produced intrinsic information, immediate feedback may reduce the individual's ability to detect self-errors and block self-objective assessing of the trial, and then have a negative effect on motor learning [13]. Therefore, it is clinically recommended to consider an interval between the trial and the feedback to make the response-produced information processing possible. Since the 1970s, many researchers suggested that learners' sensitivity to discover and correct their errors is beneficial to motor performance and motor learning [13].

Thereafter, several studies examined the effects of self-estimation on limb motor learning. Theoretically, when the learner did the motor action and even while doing it, the response-produced information from internal sources associates with extrinsic feedback information about the achievement/non-achievement of the environmental goal, and gradually the learner acquires the ability to discover her/his errors by matching these two types of information. Detecting the error can be useful in several ways. If the learner identifies the errors in the initial trials and tries to correct them, he/she can act more accurately in subsequent trials and have a better performance in delayed retention tests [15].

On the other hand, the ability to detect errors provides a situation to the learner to use response-produced intrinsic information as well as extrinsic feedback information and thus, the learner is less dependent on extrinsic feedback, which results in better performance in no feedback situations [13, 15].

Studies on the effects of feedback timing on limb motor learning revealed that immediate feedback results in high rate of motor skill acquisition, but delayed feedback causes better results in the retention and the transfer tests; therefore, the degradation of performance from the acquisition phase to the retention phase are less. Hula et al. performed the first study to investigate the effect of feedback timing on speech motor learning. They used an experimental-single subject design on two subjects with apraxia of speech in order to compare the effect of immediate and delayed feedback (with five seconds delay).

The results were inconsistent for one of the participants, but for the other participant, results indicated that immediate feedback increases the acquisition rate and delayed feedback results in more permanent outcomes. They stated that the complexity of the stimuli may affect the results and makes them difficult to interpret; in addition, the small sample makes it difficult to generalize the results [2, 7]. To the best of authors' knowledge, no study thus far reported the effect of feedback timing on speech motor learning.

Some studies focus on the interval between the movement and the delayed extrinsic feedback [15-21]. This interval may be spent simply without performing any specific activity or with a special activity such as counting [19]. One interesting activity to fill this interval is the estimation of results by the learner, so that the learner comments on reaching/not reaching the goal before receiving the feedback. Few studies focused on the effect of the result estimation on limb motor learning and revealed that the chance of self-estimation can lead to improved performance at the retention phase and increase the permanency of the results [13, 15, 22]. Based on the review of the literature, no study thus far reported the effect of self-estimation on speech motor learning before receiving feedback.

As mentioned earlier, there is little evidence of the effect of the feedback timing on speech motor learning and no study was conducted thus far on the effects of self-estimation on speech motor learning. Therefore, the current study investigated the effects of KR timing and self-estimation on learning a new speech motor skill before receiving KR in healthy adults. Determining the important variables and optimal conditions of speech motor learning can have widespread clinical applications, because speech and language therapists can easily make changes in the condition of providing feedback and improving motor learning without additional costs.

2. Methods

Participants

In the current study, 39 healthy adults (20 to 34 years old) participated. Sample size was estimated based on the acquisition of variable in Steinhour and Grayhack's study, and considering the significance level of 0.05 and the study power of 0.08. Participants were selected by the convenience sampling method; they were Persian monolingual individuals from a university community and, according to their reports, had no history of speech, language, or hearing apparent impairments. Also, they had no experience of French language learning. Participants were randomly divided into three groups: the group 1 received immediate KR feedback, the group 2 received delayed KR feedback after eight seconds, and the group 3 received delayed feedback after eight seconds with the opportunity of self-estimation.

Stimuli

The French /ɪn/ phoneme was used as a new speech motor task. This phoneme is a semivowel and has an oro-nasal production manner, which is not present in Persian. Twenty-three French words with syllabic structure similar to Persian language rules (i.e. the absence of the consonant clusters or the vowels in the initial position of words) or simplified to match the Persian language rules were selected. The target sound came only once in each word in the initial, middle, or final positions of the word. Fifteen words were randomly selected as training stimuli for the acquisition phase, and eight words remained untrained for the transfer test. The 23 target words are included in Appendix A.

The criteria for judging the correctness of each attempt were as follows: 1. Production of the word without stuttering, repetition, and correction; 2. Natural duration of the word; 3. Natural stress of the word; 4. The correct production of the target phoneme. The target words were typed in English with black pencil and in easily readable font and size, and the target sound was marked in red. At each training session, each word was practiced seven times (a total of 105 trials) [5]. A random arrangement of these 105 trials was made for each training session, and the same arrangements were used for all participants. All training sessions and retention/ transfer tests were recorded as audio files. Providing of KR was online and alive, but calculation of the scores was done later, according to audio files.

Procedures

The training sessions and retention/transfer tests were held in an acoustic room of a speech and language laboratory. Each participant sat on the chair in front of a monitor and beside the trainer. Target words were presented as a PowerPoint file. Number of sessions and number and type of practices were the same for all three groups. A Persian-French bilingual person with the experience of French language teaching produced the target sound and words clearly and intelligibly, and his voice was recorded and used as a model of correct production of the target sounds and words.

All groups received random practice and had four sessions of approximately 40-50 minutes in one week. Approximately, the first 10 minutes of each session was devoted to pre-practice. In pre-practice, the phonetic place of the target phoneme was introduced and the correct production of the phoneme and the training words were practiced until the learner produced correct /ɪn/ three times. The participants received KP as well as KR feedback in pre-practice. Then 30-40 minutes were allocated to the practice. The practice included 105 trials in which the learner was not given any model for correct production or KP feedback.

The words were presented to participants randomly and the participants should produce them and receive feedback based on the group performance. Before training, the subjects were informed that their performance (if received KR) is graded by the trainer as good, not bad, and bad. The provided verbal KR after each practice was scored 0 for bad, 0.5 for not bad, and 1 for good trials. At the end of each session, the final score for each session (maximum 105) was recorded. Maximum possible score for transfer test was 8 (for eight untrained words). The rater re-scored an audio file of 105 trials after four weeks and Pearson correlation test was used to assess the validity of the trainer's judgments, and the correlation coefficient of his repeated judgments was 0.90.

Transfer and retention tests were used to examine the generalization as well as the permanency of learning outcomes. The transfer test was performed five minutes after the final training session and two retention tests were performed one day and two weeks after the final training session. All three tests were administered in no model and no feedback (KR or KP) situations. The Kolmogorov-Smirnov test was used to evaluate the normality of the data and the Leven test was employed to check the homogeneity of the variances. Repeated-measures ANOVA was used to investigate the effect of KR timing on two acquisition and retention phases and one-way ANOVA was used to examine the effect of KR timing on the transfer of the results.

3. Results

To investigate the effect of KR timing on learning the new sound, repeated measures ANOVA was used. The results of ANOVA for the acquisition and retention phases are summarized in Table 1. The results of the test demonstrated significant differences between groups in both acquisition and retention phases.

The post hoc Tukey test showed significant difference between groups 1 and 2 at both acquisition and retention phases ($P<0.05$). The group 3 had no significant differences with the other two groups (Table 2).

Table 1. Results of ANOVA on the effect of feedback timing over time

Variables	P	F	df
Acquisition phase	0.04	3.519	2
Retention phase	0.04	3.397	2

The significant level was 0.05; df: degree of freedom

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The mean score difference (Dif 1) of the 1st and the 4th training sessions as well as Dif 2 and Dif 3 (the 4th training session, and the 1st and 2nd retention tests mean scores) were calculated and examined to determine which groups obtained better scores in each phases. As mentioned above, only groups 1 and 2 were significantly different and according to Table 3, the group 2 had better scores in both acquisition and retention phase in comparison with group 1.

In addition, one-way ANOVA was performed for the mean scores of the transfer test and the result of the test showed a significant difference between at least two groups (P=0.001, F=13.024, df=2). Groups 2 and 3 were not significantly different. Table 3 shows that the highest and the lowest mean scores in the transfer test belonged to groups 2 and 1, respectively. The post-hoc test (Table 4) indicated that the mean score of transfer test in group 1 was significantly different from those of the other two groups.

Table 2. Multiple comparisons between groups

(I) Timing	(J) Timing	Acquisition Phase			Retention Phase		
		Mean Difference (I- J)	Std. Error	Sig.	Mean Difference (I-J)	Std. Error	Sig.
Group 1	Group 2	-10.4058	3.92459	0.031	-11.6795	4.64194	0.043
	Group 3	-5.5019	3.92459	0.351	-8.5769	4.64194	0.169
Group 2	Group 1	10.4058	3.92459	0.031	11.6795	4.64194	0.043
	Group 3	4.9038	3.92459	0.433	3.1026	4.64194	0.783

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Table 3. Difference of mean scores and mean scores of transfer test for each group

Group	Dif 1			Dif 2			Dif 3			Transfer		
	G1	G2	G3	G1	G2	G3	G1	G2	G3	G1	G2	G3
Mean	23.73	20.23	21.00	-7.23	-1.00	0.07	-10.03	-8.96	-6.57	3.26	5.26	5.15
SD	12.23	110.6	18.62	6.04	6.71	2.36	2.39	2.08	3.74	1.28	0.97	1.08

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Table 4. Multiple comparisons between the groups

(I) Timing	(J) Timing	Mean Difference (I-J)	Std. Error	Sig.
Group 1	Group 2	-2.00000	0.44003	0.000
	Group 3	-1.88462	0.44003	0.000
Group 2	Group 1	2.00000	0.44003	0.000
	Group 3	0.11538	0.44003	0.963

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4. Discussion

The main purpose of the current study was to determine the effect of the KR timing on acquisition, retention, and transfer of speech motor learning in healthy adults; moreover, the effect of estimating the result before receiving KR feedback was investigated in other phases of the study. Regarding previous studies on limb and speech motor learning, it was expected that immediate feedback results in quicker acquiring speech task and providing delayed feedback, especially after self-estimation, which lead to more permanent learning at the retention phase and facilitate the transfer of learning to untrained items.

The current study revealed that motor performance and motor learning in acquisition and retention phases were significantly different among the groups. Immediately received KR and delayed received KR (without self-estimation) differ significantly between various groups. Examination of the effect of KR timing on limb and speech motor learning [2, 14, 16, 18, 19] showed that although the immediate KR promotes the rate of the acquisition, but the delayed KR is more effective for retention of new motor skill.

Consistent with the results of studies by Kim et al., Hula et al., Anderson et al. [23], Adams et al., Liu and Wisberg, and Swinnen et al. the obtained mean scores at the acquisition phase indicated that receiving immediate feedback resulted in better performance at acquisition phase rather than the delayed feedback; moreover, delayed feedback (without self-estimation) resulted in better performance at retention phases. In addition, the mean scores in the transfer test indicated that delayed feedback-with/without the opportunity to estimate the result before receiving extrinsic feedback-was more beneficial for transfer of learning to untrained items relative to the immediate feedback. Thus, results of the present study indicated that although immediate feedback may increase the acquisition rate, delayed feedback is more beneficial for sustain ability and transfer of learning and causes less degradation of performance over time.

Theoretically, it seems that providing an opportunity for self-estimation helps learner to process intrinsic feedback of the motor action for estimating the result and discovering errors in the first stages of training and it corrects errors in subsequent trials. However, in the absence of feedback, it has better performance and can use the recently acquired ability in untrained items. In contrast, providing immediate feedback by blocking the process of intrinsic feedback leads to learner's dependence on external information about the result and in conditions where extrinsic feedback is not available, the performance of the learner is significantly reduced over time.

Contrary to previous studies showing better performance at the retention phase for group with self-estimation opportunity (e.g. Chiviacowsky and Wulf [24], Guadangnoli and Kohl, and Liu and Wisberg) the current study showed that delayed KR after self-estimation and empty delayed KR were equally at three acquisition, retention, and transfer phases and the differences between immediate KR and delayed KR after self-estimation was only at the transfer test. As described earlier, one of the groups received delayed feedback without self-estimation opportunity.

In fact, the interval between the practice and receiving the feedback (eight seconds) was an empty interval and there was no specific activity for this. Individuals may spend this interval in different ways; actually learners may be silent spontaneous estimation at this interval. So, the differences between the two situations (delayed feedback with or without self-estimation) may actually be fewer. Therefore, it is suggested that future studies can minimize the impact of this factor by considering another group and providing an activity, which interferes with the silent result estimation process, such as a reversal counting task.

The present study encountered some limitations. First, in each training session, there were 105 trials that were frustrating for some of the participants. Second, considering one of the groups immediately received KR and all the feedbacks were verbal, practice exercises were judged by just one individual to provide immediate KR. Finally, judgments were made based on practice exercises with perceptual assessment methods. Although perceptual assessment is one of the most important and commonly used tools for speech therapy, it is always associated with the probability of error.

5. Conclusion

The present study suggests that immediate KR is beneficial for speech motor acquisition and delayed feedback is more beneficial for retention and transfer of speech motor learning.

Ethical Considerations

Compliance with ethical guidelines

All participants filled a consent form to confirm their voluntarily participation in the study. Accordingly, authors were committed to keep the participants information confidential. The study protocol was approved by the Ethics Committee of Ahvaz Jundishapur University of Medical Sciences (code: PHT-9511).

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Authors' contributions

All authors contributed in designing, running, and writing all parts of the research.

Conflict of interest

The authors declared no conflict of interest.

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Appendix A. French words stimulus used in the study and the description of their syllable structure

Word	Syllable Structure
Ateqesan	CV CV CV CVC
Akapabl	CV CV CVCC
Ateqioq	CV CV CV CVC
Aseqtan	CV CVC CVC
Ateqvio	CV CVC CV CV
Azhenioq	CV CV CV CVC
Adigo	CV CV CV
peqAs	CV CVC
sAtuq	CV CVC
lAzhqi	CVC CV
dAdon	CV CVC
lAguistik	CV CV CVC CVC
sudA	CV CV
peqA	CV CV
maqA	CV CV
kuzA	CV CV
kontqA	CVCC CV
mAsiq	CV CVC
tAtamaq	CV CV CVC
vAdikt	CV CVCC
moA	CV CV
seqtA	CVC CV
zhaghdA	CVC CV

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