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The Learning Process in Biofeedback: Is It Feed-Forward or Feedback?

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Twenty participants responded to inquiries about strategies used, and thoughts during, each of three electromyograph biofeedback sessions. The purpose of the study was to learn more about what individuals report doing during biofeedback and, specifically, to determine if individuals construct a response using feedback to sense subtle differences in muscle tension (feedback processes), or select a response from an existing repertoire using feedback primarily for confirmation (feed-forward processes). Protocol analyses found considerable support for feed-forward processes and little support for feedback processes. Such results are important because early reliance on feed-forward processes may result in limited control and limited transfer.

Descriptor Key Words: EMG biofeedback; learning in biofeedback; verbal reports; feedforward processes; feedback processes.

Although biofeedback has become a very popular therapeutic treatment for a variety of psychological and physical problems, equivocal research findings have prompted Miller (1982), among others, to call for research that attends more to the learning processes involved. In this vein, both Meichenbaum (1976) and later Turk, Meichenbaum, and Berman (1979) stated that we need to pay more attention to individual cognitions during the phases of biofeedback. Analyses of these cognitions could indicate both affective

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reactions and actual capabilities that might correlate with differences in the variable under investigation, and thus provide greater insight regarding the "active ingredient" in biofeedback.

Of course, such inquiries are relevant to the extent that subjective awareness is present in biofeedback. Most explanations for what happens in biofeedback see the instrumentation providing detailed information regarding subtle changes in physiological activity that, heretofore, were not discriminated by the individual. With this new information the individual learns to recognize these subtle differences and develops a response to control this activity (e.g., Basmajian, 1979; Surwit, Williams, & Shapiro, 1982).

The existence of feedback logically suggests that what happens after a particular response will influence the individual to behave in certain ways. It is not surprising that operant explanations have predominated regarding learning in biofeedback, leading also to expectations that individuals would be aware, at least to some extent, of what they were doing in biofeedback. This does not dispute the view that some processes will occur without awareness. Indeed, research in cognitive psychology demonstrates that having "classified" a particular stimulus, an individual may execute "productions" stored in long-term memory associated with this classification (Rumelhart & Ortony, 1977). These productions, which could be either intellectual or motor skills, may be executed with a high degree of automoticity. In such instances it would not be surprising that participants were unable to report what they were doing. Nevertheless, it is certainly worthwhile to investigate cognitive awareness as it may be reflected in biofeedback.

Roberts and Marlin (1979) note that studies asking participants to report what they are doing in biofeedback have not produced conclusive results. In order to improve on these prior studies we have used two prominent models of the learning process during biofeedback (Brener, 1977; La Croix, 1981) as guides in developing criterion items to use for analyzing individual protocols.

Briefly, it is Brener's (1977) view that control of a response in biofeedback follows after the ability to discriminate response-related afferentation, and that the appropriate response images are formulated on the basis of this afferentation process. Although LaCroix does believe that control can occur through afferentation, it is his contention that it occurs primarily through efferent processes. According to La Croix (1981), various stimulus elements presented to the individual before biofeedback, including experimental instructions, help to identify already existing behaviors. The individual tries out these existing responses, and acquisition of control then proceeds if the exteroceptive feedback indicates some success. In more recent work, La Croix (1984) has substituted the terms *feedback* and *feed-forward* for the previously mentioned *afferent* and *efferent* processes, respectively. These changes provide more consistency in terminology between La Croix and Brener.

It should be mentioned that feedback and feed-forward processes are not being presented here as mutually exclusive. Feed-forward processes can be viewed as the flow of information from input through to output, and a feed-forward path exists if there is a relationship between input and output. However, one infers the existence of feed-forward processes through feedback regarding the output (Mulholland, 1977). Within this framework, what can it mean to say that feedback or feed-forward processes predominate in biofeedback?

If feedback processes predominate (the original Brener position), an individual would be constructing a new response and this response would be preceded by learning to discriminate subtle differences in physiological sensations with the availability of fine-grained feedback. This would be a closed-loop system wherein feedback guides the development and optimization of a feed-forward path (Mulholland, 1977). On the other hand, if feed-forward processes predominate (the La Croix position), an individual would select and try out a response that he or she already knows, and instead of becoming more aware of subtle physiological sensations with the aid of fine-grained feedback, the individual would use the feedback primarily as confirmation that a particular response was working.

While feed-forward processes indicate an open-loop system (Mulholland, 1977), strictly speaking, we cannot call biofeedback open-looped because of the existence of feedback. Instead, when feed-forward processes predominate, the individual executes a response for which feedback provides early evidence of a feed-forward path. After this point less attention will be paid to feedback, particularly those efforts to associate feedback to subtle differences in the physiological variable. Essentially, within the context discussed here, more of the feedback message is attended to and processed during feedback processes, while less of the feedback message is attended to and processed during feed-forward processes.

In this study, participants were asked to provide anticipatory, concurrent, and retrospective verbalizations of cognitions during electromyograph (EMG) biofeedback, and these verbal protocols were analyzed to determine whether feedback or feed-forward processes predominated.

METHOD

Subjects

Participants in this study were 20 upper-level undergraduate students, 15 females and 5 males, enrolled in two different courses in an educational psychology department. All participants were volunteers and received $15 if they completed the three sessions.

Instrumentation

The biofeedback apparatus used was an Autogen 1700 Electromyograph. Two active electrodes were placed on the forehead about 3 or 4 inches apart, with the reference or grounding electrode placed between the active electrodes. The feedback was a continuous tone that decreased or increased in intensity as muscle tension decreased or increased. When the muscle tension level either exceeded or went below a particular predetermined threshold level, depending on the experimental condition, the audio signal was terminated. In addition, an Autogen 5100 Integrator/Wave Form Analyzer, interfaced to the biofeedback unit, monitored and displayed averaged microvolt readings over specified time intervals.

Procedure

Each participant received three EMG biofeedback sessions. The procedures in each session were as follows:

Session I

1. Brief introduction to the research study and general information about biofeedback.
2. Five-minute baseline period.
3. Question asked for baseline: "How would you describe what's going through your mind now regarding this biofeedback task?" (answer tape-recorded).
4. Ten-minute biofeedback session; threshold set 25% below average baseline. Instructions: "Try to keep the sound off as much as possible."
5. After 10 minutes of biofeedback, question: "What were you thinking about during the last few minutes?" (answer tape-recorded).
6. Ten-minute biofeedback session; same conditions as in number 4 above.
7. After biofeedback, two more questions: (a) "What were you thinking about during the last few minutes?" (b) "What were you doing to keep the sound off?" (answers tape-recorded).

Session II

1. Five-minute baseline period.
2. Question asked after baseline: "How would you describe what's going through your mind now regarding this biofeedback task?" (answer tape-recorded).

3. Twenty-minute biofeedback session; threshold set 25% below average baseline. Instructions: "This will be about a twenty-minute session and during this time try to keep the sound off as much as possible."
4. After biofeedback, question: "What were you doing during the biofeedback session to keep the sound off?" (answer tape-recorded).

Session III

1. Five-minute baseline period.
2. Question asked after baseline: "How would you describe what's going through your mind now regarding this biofeedback task?" (answer tape-recorded).
3. Five-minute biofeedback session; threshold set at the average baseline. For this 5 minutes the audio feedback was set to go off when an EMG reading exceeding threshold, thus a reversal procedure. Instructions: "During the biofeedback try to keep the sound off as much as possible."
4. After the 5-minute session, question: "What were you thinking about during the last minute or so?" (answer tape-recorded).
5. Fifteen-minute biofeedback session; threshold set at 25% below baseline and a return to normal procedure of audio feedback going off when an EMG reading went below threshold. Instructions: "This will be about a fifteen-minute session and during this time try to keep the sound off as much as possible."
6. Question asked after the 15-minute session: "What were you doing during the last biofeedback session to keep the sound off?" (answer tape-recorded).

During each biofeedback session the Autogen 5100 Integrator/Wave Form Analyzer displayed an averaged microvolt reading every minute to the experimenter only. In this way the participant's performance could be monitored throughout the three sessions. Sessions were separated by a week, but in two cases the separation between the second and third sessions was 2 weeks.

RESULTS

Comparisons of EMG levels during baseline and biofeedback training are depicted in Table I. The training EMGs for each session are mean values for the last 5 minutes of biofeedback.

Quite evident in Table I are the lower EMG levels during biofeedback relative to baseline. A 2 × 3 analysis of variance, with repeated measures on the second factor (i.e., sessions) yielded a significant main effect (F = 13.98, p = .001) for baseline versus training; however, there was no sessions effect or interaction. Therefore, while biofeedback did result in lower EMG levels, these differences were uniform across all three sessions.

Verbal protocols for all participants and sessions were transcribed and analyzed. Since the primary question related to what participants were doing during biofeedback, the most important analyses were of the last two questions of the first session and the last question of sessions II and III. Since the last two questions of the first session related to the same content in the same time period, they were counted as one overall response. The theoretical views of feedback and feed-forward learning processes served as bases for developing criterion items that judges used in considering the protocols. The criterion items were as follows:

A. This individual was constructing or building a new response or strategy.
B. This individual was trying out a response or strategy that he/she already knew.
C. This individual was using the feedback to learn to sense and actually be aware of differences in muscle tension.
D. This individual was using the feedback as information that reported differences in muscle tension.

Judges assigned a value to each item in the following manner: 5 = agree, 4 = agree somewhat, 3 = not sure or cannot determine, 2 = disagree somewhat, 1 = disagree. Agreeing with items A and C would provide support for feedback processing (Brener's position), while agreeing with items B and D would provide support for feed-forward processing (La Croix's position).

Two different analyses were undertaken. In the first analysis, judges made decisions about each session separately, while in the second analysis, judges made global decisions across the three sessions.

For the first analysis, four judges (a professor in an educational psychology department and three doctoral students in the same department)

Table I. Mean Baseline and Training (Last 5 Minutes) EMGs for the Three Sessions

Session	Baseline	Training
I	2.44	2.10
II	2.39	1.81
III	2.35	1.62

assigned values for each criterion item to each of 60 protocol statements. The total of 60 included 3 statements, 1 for each session for each of the 20 participants. At the time of the analyses, the graduate students were unaware of the theoretical controversy involved. However, the judgment process made them very aware of the controversy. All four judges reported no particular bias regardless of the extent of naivete when making judgments.

In presenting data for comparison purposes, ratings of 1 and 2 have been combined to indicate a disagree value, and ratings of 4 and 5 have been combined to indicate an agree value. The frequency of "agree," "disagree," and "not sure" ratings of the four judges for items A, B, C, and D, as well as percentages for totals, are depicted in Table II.

Noteworthy in this table is that total frequencies for the items indicate agreement with a feed-forward process (items B and D) and disagreement with a feedback process (items A and C). These are not unanimous decisions, of course. For example, there were a considerable number of agreement judgments (59) for item A. That is, of the 240 protocol decisions regarding item A (60 sessions × 4 judges), 59 (24.6%) were believed to be indicative of constructing or building a new response. It should also be pointed out that these judgments were often difficult to make. Approximatley 40% of the decisions for items A, B, and C were in the "not sure" category.

Nevertheless, there does appear to be substantial evidence indicating a predominance of feed-forward processes. The patterns in items B, C, and D are distinct in this regard. Chi-square analyses comparing total agree or disagree frequencies for items A, B, C, and D provide further support in this regard. All four chi-square analyses were significant (item A at the .05 level and items B, C, and D beyond the .001 level).

For the second analysis of protocol statements, three judges (the same professor and two of the same doctoral students) assigned values for criterion items A, B, C, and D, but this time a global judgment across the three sessions was made. This second analysis occurred several months after the first analysis, and judges did not have access to their prior deliberations. The frequency of "agree," "disagree," and "not sure" global ratings of the three judges for items A, B, C, and D, as well as percentages for totals, are depicted in Table III.

As one can see from an inspection of Table III, the pattern is similar to the first analysis—that is, more judgments in agreement with and fewer in disagreement with feed-forward processes (items B and D), while fewer judgments in agreement with and more in disagreement with feedback processes (items A and C). Chi-square analyses comparing the agree–disagree frequencies for items A, B, C, and D support this view for the most part. Only the chi-square analysis for item A did not yield significance at at least the .05 level of significance, while the chi-square values for items B, C, and D were all significant beyond the .001 level of significance.

Table II. Frequency of Agree, Disagree, and Not Sure Ratings of the Four Judges for Items A, B, C, and D and Percentages for Totals

	A			B			C			D		
Judge	Agree	Disagree	Not sure	Agree	Disagree	Not sure	Agree	Disagree	Not sure	Agree	Disagree	Not sure
1	10	29	21	38	3	19	2	30	28	35	3	22
2	22	14	24	24	13	23	3	15	42	29	3	28
3	12	25	23	33	7	20	23	20	17	34	14	12
4	15	17	28	24	3	33	14	39	7	32	21	7
Totals	59[a]	85	96	119[b]	26	95	42[b]	104	94	130[b]	41	69
	(24.6)	(35.4)	(40.0)	(49.6)	(10.2)	(39.6)	(17.5)	(43.3)	(39.2)	(54.2)	(17.1)	(28.8)

[a]Chi square significant at .05 level.
[b]Chi square significant at .001 level.

Table III. Frequency of Agree, Disagree, and Not Sure *Global* Ratings of the Three Judges for Items A, B, C, and D and Percentages for Totals

	A			B			C			D		
Judge	Agree	Disagree	Not sure	Agree	Disagree	Not sure	Agree	Disagree	Not sure	Agree	Disagree	Not sure
1	5	8	7	15	1	4	2	12	6	16	0	4
2	3	13	4	14	2	4	7	11	2	14	3	3
3	11	3	6	16	0	4	4	14	2	13	5	2
Totals	19 (31.6)	24 (40.0)	17 (28.3)	45[a] (75.0)	3 (5.0)	12 (20.0)	13[a] (21.7)	37 (61.7)	10 (16.7)	43[a] (71.7)	8 (13.3)	9 (15.0)

[a]Chi square significant at .001 level.

An interrater reliability check among the three judges for the second analysis indicated 87% concurring decisions between judges 1 and 2, 86% between 1 and 3, and 67% between 2 and 3. A concurring decision for a particular individual was one in which both judges "agreed," both judges "disagreed," or both "could not decide." A dissenting decision was one in which a judge agreed and the other disagreed. Instances in which a judge "could not decide" but the other either agreed or disagreed were not counted in the reliability check.

Therefore, whether judges made decisions about individual sessions or made global decisions across all three sessions, (a) they saw considerable evidence that participants were trying out strategies they already knew (B) and relatively little disagreement in this regard; (b) they did not see much evidence of participants using feedback to learn to sense and actually be aware of differences in muscle tension (C); and (c) they saw considerable evidence of participants using feedback as information (D) that reported differences in muscle tension.

As to whether or not participants were constructing or building a new response (A), the judgments were less clear in that there was significant disagreement that this was happening in the analysis of separate sessions but not so for global judgments.

In addition to questions regarding what was going on during biofeedback, the question "How would you describe what's going through your mind now regarding this biofeedback task?" was asked before biofeedback began in each of the three sessions. The purpose of these inquiries was to determine if there were any significant cognitions before biofeedback that might relate in some meaningful fashion to performance during biofeedback.

Briefly, there is very little to report. Not much could be learned from these statements. Most participants reported being either curious, interested, or concerned about the value of the study, and/or feeling relaxed after baseline.

Another question, "What were you thinking about during the last minute or so?" was asked after the first 5 minutes of biofeedback in the third session. During that 5 minutes of biofeedback, participants were instructed to "keep the sound off as much as possible." However, unknown to the participants, this was a reversal procedure in that audio feedback was set to go off when an EMG reading exceeded the threshold value. This "control" procedure was used to verify that there was a relationship between biofeedback procedures and awareness of the participants. For example, if participants had already identified and had been using a strategy that was working, would they notice that it was not working during that session?

An inspection of the protocols indicated that 11 of the 20 participants definitely noticed that something was different. Of these 11, 2 knew exactly what the procedure was; that is, they knew that the procedure had been revers-

ed and they now had to increase muscle tension to turn the sound off. Four of the remaining 9 participants said nothing at all that could be interpreted as noticing something was different. Three did recognize difficulty in getting the sound to go off, but since they did not compare the third session with other sessions we cannot conclude that they noticed a difference in the third session. The remaining 2 protocols were brief and unintelligible.

DISCUSSION AND CONCLUSIONS

This study represented an attempt at analyzing verbal protocols to determine what individuals report doing during biofeedback. In analyzing protocols, judges found little evidence for feedback processes but considerable evidence for feed-forward processes as defined by La Croix (1984). These results support La Croix's (1984) view that if a search through one's long-term memory store yields a likely candidate response, this response will be executed, and if the feedback signal indicates success, the response will be continued. He further adds that with successful external feedback the individual will not pay much attention to feedback information from interoceptive afferentation. It is this latter idea that was addressed in item C: "This individual was using the feedback to learn to sense and actually be aware of differences in muscle tension."

That judges did not see much of C in the protocols does not rule out the possibility that participants were doing it. The lack of a fluent verbal repertoire regarding subtle differences in muscle tension may have contributed to the number of "not sure" judgments, thereby masking attempts to use feedback in sensing these differences. However, the substantial number of judgments agreeing with D, "This individual was using the feedback as information that reported differences in muscle tension," certainly indicates that many participants were making at least some use of the feedback. The key issue, it seems, is whether biofeedback, in these situations, facilitated learning of subtle discrimination in physiological activity.

If an individual does not fully attend to feedback messages, how would we expect this to affect what is learned in biofeedback? How would it affect control of the physiological process in question? One way of looking at this issue is in terms of error. If there is no feedback from physiological processes back to the central nervous system (CNS), errors in the execution of a response cannot be corrected. To the extent that errors cannot be corrected, control is decreased (Mulholland, 1984). If feedback from exteroceptors is attended to for confirmation only, there is loss of information in the system. This loss of information will result in less control. There may be improvement in control since some feedback was adhered to, and there indeed may be a feed-forward path in that a reliable relationship exists between input

(the excution of the selected response) and output (increased control of frontalis muscle tension). However, without continued attempts to associate exteroceptive feedback with subtle changes in the response, substantial error will remain and control will be limited.

A further limitation of this type of learning would be a reduction in the effectiveness of transfer. After biofeedback training an individual should be able to execute a response to reduce muscle tension without biofeedback instrumentation. There should also be an increase in control of muscle tension (i.e., reduction in muscle tension and/or less variation) due to the existence of a reliable feed-forward path. However, if during biofeedback training the information provided by fine-grain biofeedback was not fully attended to, it is likely that (a) the individual was not able to fine-tune the response (the feed-forward path) during training, (b) the individual did not learn to judge the effectiveness of the response without biofeedback instrumentation, and (c) the individual will not be able to sense the need for executing a particular response without biofeedback instrumentation.

One argument with the conclusion that feed-forward processes predominate is that there were only three sessions and that with many more sessions, over an extended period of time, participants might have provided more evidence of learning subtle discrimination in muscle tension. However, what would be the rationale for supposing that the learning process would change over time from primarily feed-forward to primarily feedback processes? La Croix (1981, 1984) provides convincing arguments that, regardless of number of sessions, feedback processes in biofeedback, although possible, will occur only rarely.

Additional analyses of the data in this study lend no support for a trend in the change of the learning process itself. In these analyses, chi-square tests of independence were run for each criterion item, to investigate the relationship between patterns of "agree," "disagree," and "cannot say" decisions over the three sessions. The resultant chi squares for items A, B, and C were not significant, thereby indicating no relationship between patterns of judges' decisions and the progression of sessions. A significant chi square was found for item D (9.82, $p = .05$). However, investigation of the individual cells in the contingency table indicates that the greatest observed versus expected discrepancies were found in the number of disagree decisions for session 1 (22) and disagree decisions for session 3 (7). If anything, these results suggest that the processes of learning during biofeedback are going more in the direction of feed-forward processes, with no trend toward feedback processes over time.

In this study we used threshold feedback. The instructions were to keep the sound off as much as possible. This type of feedback was used because it provided very little guidance as to how to negotiate the task. Also, when

using the reversal procedure (that is, to keep the sound off one had to increase muscle tension), the instructions could remain the same. Could this type of feedback have biased the results so that participants were more likely to use existing strategies rather than construct new ones? Recent work by Utz (1985) suggests that this is unlikely. In this study about the effect of instructions on cognitive processes in biofeedback, Utz used a continuous tone for feedback and essentially replicated the findings of considerable feed-forward processes and little evidence of feedback processes in participants' protocols.

In conclusion, feed-forward and feedback processes both occur in biofeedback. It is supposed to be the fine-grained feedback in biofeedback that allows for development and refinement of a feed-forward path. This refinement can be seen in more control of the physiological variable and, correspondingly, less error in the system (Mulholland, 1977, 1984). However, results of this study indicate that an early selection of an already existing response and the execution of that response essentially reduces reliance on feedback processes and emphasizes feed-forward processes. As such, it is less likely that the individual will have learned to sense subtle difference in muscle tension, thereby limiting control and transfer.

REFERENCES

Basmajian, J. V. (Ed.). (1979). *Biofeedback: Principles and practice for clinicians.* Baltimore: Williams & Wilkins.

Brener, J. (1977). Sensory and perceptual determinants of voluntary visceral control. In G. E. Schwartz & J. Beatty (Eds.), *Biofeedback: Theory and research* (pp. 29-66). New York: Academic Press.

La Croix, J. M. (1981). The acquisition of autonomic control through biofeedback: The case against an afferent process and a two process alternative. *Psychophysiology, 18,* 573-587.

La Croix, J. M. (1984). *Mechanisms of biofeedback control: On the importance of verbal (conscious) processing.* Manuscript submitted for publication.

Meichenbaum, D. (1976). Cognitive factors in biofeedback therapy. *Biofeedback and Self-Regulation, 1,* 201-216.

Miller, N. E. (1982). Some directions for clinical and experimental research in biofeedback. In L. White & B. Tursky (Eds.), *Clinical biofeedback: Efficacy and mechanisms.* New York: Guilford Press.

Mulholland, T. (1977). Biofeedback as scientific method. In G. E. Schwartz & J. Beatty (Eds.), *Biofeedback: Theory and research* (pp. 9-28). New York: Academic Press.

Mulholland, T. (1984). Concepts of control in biofeedback. In Th. Elbert, R. Rochstroh, W. Lutzenberger, & N. Birbaumer (Eds.), *Self-regulation of the brain and behavior* (pp. 277-295). New York: Springer-Verlag.

Roberts, E. R., & Marlin, R. G. (1979). Some comments on the self-description of visceral response states. In N. Birbaumer & H. Kimmel (Eds.), *Biofeedback and self-regulation.* Hillsdale, New Jersey: Erlbaum.

Rumelhart, D. E., & Ortony, A. (1977). The representation of knowledge in memory. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), *Schooling and the acquisition of knowledge.* Hillsdale, New Jersey: Erlbaum.

Surwit, R. S., Williams, R. B., & Shapiro, D. (1982). *Behavioral approaches to cardiovascular disease.* New York: Academic Press.

Turk, D. C., Meichenbaum, D. H., & Berman, W. H. (1979). Application of biofeedback for the regulation of pain: A critical review. *Psychological Bulletin, 86,* 1322-1338.

Utz, S. W. (1985). *The effect of instructions on cognitive strategies and performance in electromyograph biofeedback.* Unpublished doctoral dissertation, University of Toledo.

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