Electromyographic Biofeedback for Neuromuscular Reeducation in the Hemiplegic Stroke Patient: A Meta-Analysis

Randal E. Schleenbaker, MD, Arch G. Mainous III, PhD


The efficacy of electromyographic biofeedback (EMG-BF) for neuromuscular reeducation in the stroke patient has been difficult to establish. The purpose of this study was to assess EMG-BF efficacy through meta-analysis. We searched the English-language clinical studies of biofeedback, stroke, and cerebral vascular disease between 1966 and 1991 using MEDLINE, PsycINFO, REHABDATA, and Dissertation Abstracts International. Studies were included in the analysis if (1) the patients sustained a cerebral vascular accident that resulted in hemiplegia, (2) the study had a randomized or matched control group, (3) the study measured a functional outcome, and (4) EMG-BF was the independent variable. Eight studies met the inclusion criteria (n = 192). Their average effect size was 0.81. The 95% confidence interval for the effect size was 0.5 to 1.12. These results indicate that EMG-BF is an effective tool for neuromuscular reeducation in the hemiplegic stroke patient.

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Almost 400,000 Americans suffer strokes each year, and 38% of that number die within the first month after the stroke. The incidence of stroke appears to be decreasing, but more persons are surviving strokes. More than half of persons who survive the acute onset of stroke are alive 5 years later. With this large burden of impairment and disability, the personal and social costs of stroke are high.

As the number of stroke survivors increases and medical costs escalate, it becomes particularly important to identify stroke rehabilitation strategies that are effective. Electromyographic biofeedback (EMG-BF) has shown promise for neuromuscular reeducation in the stroke patient since it was first reported in 1960. Although several authors have reviewed EMG-BF as a therapeutic tool, questions remain regarding its efficacy in stroke rehabilitation. Past studies using EMG-BF as a treatment modality have been criticized because of small sample size, failure to account for spontaneous recovery, inadequate controls, and lack of functional outcome measures.

We chose meta-analysis (literally, the analysis of analyses) to integrate and synthesize the seemingly disparate findings regarding EMG-BF in stroke rehabilitation. Meta-analysis is a relatively new statistical technique that integrates the results of related studies to answer specific questions. This approach has the potential advantage of yielding more accurate, statistically stable estimates of treatment effects than any single study. A meta-analysis is particularly useful when individual study populations are small and their results are inconclusive or conflicting.

The purpose of this study was to determine whether EMG-BF improves function after stroke using meta-analysis of published studies that evaluate the effect of EMG-BF on function.

METHODS

We searched the literature for English-language clinical studies of biofeedback and stroke or cerebral vascular disease between 1966 and 1991 using MEDLINE, PsycINFO, REHABDATA, and Dissertation Abstracts International databases. Titles and abstracts were reviewed and all articles of possible relevance were retrieved and read. Bibliographies of retrieved articles and relevant textbooks were reviewed for additional citations. Criteria for inclusion were (1) original research study; (2) subjects sustained a cerebral vascular accident that resulted in hemiplegia; (3) study had a randomized or matched control group; (4) study measured a functional outcome; (5) EMG-BF was the independent variable.

Function was the most difficult criterion to define because of the variety of interpretations present in the literature. Function is a continuum ranging from improved grip strength to independently donning and buttoning a shirt. The demarcation between useful function and isolated activity is not always clear. For the purposes of this study, a functional outcome was defined as any measured outcome parameter that requires the complex neuromuscular activity necessary for executing activities of daily living or ambulation. Consequently, we excluded isolated muscle strength, range of motion, or muscle EMG activity as functional outcomes.

We examined the relationship between EMG-BF and functional improvement across studies by entering the effect size of each study into a meta-analysis. The effect size is the degree to which EMG-BF changes function within the population. The goal of computing an effect size is to obtain a pure number free of the original measurement unit with...
which we can indicate the strength of the relationship between EMG-BF and function. Following Hunter and Schmidt,14 we used the “d” statistic for effect size.

To compute a “d” effect size statistic, each study must provide certain minimal reported results. The study must report either raw data from which an effect size can be computed or the value of a significance test (eg, t test, F test, or \( \chi^2 \) for a 2 x 2 frequency table). If a study reported only a \( p \) value, the study’s reported information was insufficient to compute the effect size statistic. In several instances, we communicated with study authors to request additional information, but were unable to obtain data adequate to bring the study into compliance with the demands of the analysis.

**RESULTS**

One hundred twenty-four citations were identified, of which 58 could be considered original studies rather than technical notes, interim reports, or review articles. Only eight studies (see Appendix) met all the criteria for inclusion.

**Average Effect Size**

The table presents the characteristics and effect size of each of the eight studies. The studies in the table featured multiple outcome measures. The measure chosen from each study was the indicator of functional status that reported analyzable data. All the effect sizes are positive, suggesting that biofeedback increases functional improvement in hemiplegic stroke patients.

The meta-analysis includes a total sample of 192 cases. The average sample size is 24 and the average effect size (d) is 0.81. The average effect size weights the effect from each study by that study’s sample size. Because the effect size is in standard deviation units, individuals receiving EMG-BF exhibit increases in function above control group individuals by almost one standard deviation, or 0.81 standard deviation units. Because an effect size of 0.50 is conventionally considered to be of practical significance,15 and an effect size of >0.80 can be considered large,16 EMG-BF seems to be an effective treatment regimen for increasing function in stroke patients. The one-tailed significance level corresponding to the total set of studies suggests a highly significant effect (\( z = 4.67; p < 0.00001 \)).

With a small number of studies and relatively small total sample size, there is a potential for sampling error. The population effect size variance is the observed variance for effect sizes corrected for sampling error and is found by subtracting the sampling error variance from the observed variance. A computation of the population effect size variance was negative (−1.228), indicating that there is some second-order sampling error. Because the outcome of any meta-analysis based on a small number of studies depends to some extent on which studies randomly happen to be available, the analysis depends on study properties that vary randomly across studies. This is known as second-order sampling error. If the estimate of the population effect size variance had been positive then we would have assumed some source of nonartifactual variation across studies (ie, there is a moderator variable that needs to be considered). When, as in this case, a population effect size variance is negative, it is prudent to investigate the existence of possible moderator variables.

To determine whether the second-order sampling error was due to unresolved sampling error from the primary studies or the result of variation in effect sizes, we did a \( \chi^2 \) test for homogeneity of variance. The result was a value of 2.31 (df = 7), which falls below the finding that would show significant variation in the research domain (\( p > .05 \)). The \( \chi^2 \) results suggest that there is no moderator variable and the only artifact operating is sampling error. Because the research domain is homogeneous, the standard deviation of effect sizes is zero. Thus, the only second-order sampling error is the sampling error in the mean effect sizes. The standard error of the mean is 0.16. The confidence interval for the population effect size is

\[
.81 - 1.96(.16) < \text{population effect size} < .81 + 1.96(.16) \\
.496 < \text{population effect size} < 1.1236
\]

The confidence interval does not cross zero, suggesting that EMG-BF has a positive effect on functional improvement in hemiplegic stroke patients. An issue that arises in any meta-analysis of published studies is the possible bias caused by the availability of studies. File drawer analysis attempts to account for studies of a topic that have not been published (presumably because of disappointing results) and are sitting in file drawers. Rosenthal’s file drawer analysis17 estimates the number of unlocated studies with null results (ie, with mean d effect size = 0) that would have to exist to bring the significance level of a meta-analysis down to the lower boundary of statistical significance (\( p = 0.05 \)). In the present analysis, the number of unlocated studies required to bring the combined probability level for the group of studies to .05 is 56. Because this number is far greater than that of studies included, it appears unlikely that the file drawer effect has distorted the results of the meta-analysis.

**Comparison of Upper and Lower Extremity Data**

The data was analyzed to determine the differing effects of EMG-BF on functional outcomes in upper and lower extremities. The number of studies available for analysis is limited when the studies are stratified and analyzed in two separate groups. Consequently, a full meta-analysis of the studies according to effect size is probably inappropriate. However, it is acceptable to compute the mean effect size in a stratified analysis to supply an indication of the direction of an effect. The mean effect size (d) among studies examining the effect of EMG-BF on functional improvement in upper extremities is .77; for lower extremities, the mean effect size is .89. In both cases, the mean effect suggests that EMG-BF has a positive effect on functional outcomes.

**DISCUSSION**

Our findings indicate that EMG-BF improves functional outcomes in hemiplegic stroke patients. The effect size yielded in this analysis shows a significant improvement in function with the use of EMG-BF. This finding is particu-
larly important because the majority of the studies included were conducted with patients more than 3 months after their strokes. These patients were likely to have reached a plateau in their spontaneous neurologic recovery, yet EMG-BF seems to have improved their neuromuscular function.

The number of studies meeting inclusion criteria was insufficient to conduct individual meta-analyses for upper and lower extremities. However, the findings indicate that in both cases EMG-BF has a positive impact on function in hemiplegic stroke patients.

Although the results indicate a significant improvement in function with EMG-BF, the cost-effectiveness of this therapy is still uncertain. Optimal timing for the use of EMG-BF in the therapeutic regimen is also unknown.

Measures of function varied throughout the literature. Function can be viewed as a continuum of tasks. The demarcation between useful function and isolated activity is not always clear, in much the same way as the distinction between dependence and independence. Complex neuromuscular activities (ie, drawing a circle with the olecranon) are tasks at the less complex end of a functional continuum. We included as a minimum criteria the outcome measures that required complex neuromuscular activity needed to execute activities of daily living or ambulation. It could be argued that gait improvements or the time it takes to trace a circle with the olecranon may not represent function; however, these are complex neuromuscular activities. These tasks are not simply isolated activities that have no meaning outside themselves. The ability to draw a circle with one’s olecranon has direct bearing on the ability to use the upper extremity in a functional manner. Though other outcomes of function in stroke rehabilitation may be important (ie, sensation or fine motor control) they have not been used as functional outcome measures in control group investigations using EMG-BF as treatment for hemiplegic stroke patients.

Any interpretation of these findings should be made with an awareness of possible limitations. The technique of meta-analysis has been criticized for comparing and aggregating studies that use different outcome variables and measurements, as well as different subject populations. Meta-analysis allows one to examine mediating effects by coding for them and testing them later. In this study, we examined the data for possible moderating variables. Additionally, by using strict inclusion criteria, the included research designs were of high quality and were fairly similar (ie, randomized or matched control design).

### Studies Included in Meta-Analysis

<table>
<thead>
<tr>
<th>Trial/Year</th>
<th>n</th>
<th>Inclusion Criteria</th>
<th>Treatment Group Protocol</th>
<th>Control Group Protocol</th>
<th>Outcome Measure</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upper extremity</strong></td>
<td></td>
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<tr>
<td>Basmajian et al 1982</td>
<td>21</td>
<td>CVA &gt; 2-3 mo old, no receptive aphasia</td>
<td>15 treatments, 3/wk, 40 min sessions, PT + EMGBF</td>
<td>15 treatments, 3/wk, 40 min sessions, PT only</td>
<td>Gait analysis grading system</td>
<td>0.75</td>
</tr>
<tr>
<td>Wolf et al 1983</td>
<td>31</td>
<td>CVA &gt; 1 yr old, previous rehab, no previous BF, no receptive aphasia</td>
<td>60 treatments, 2-3/wk, 45 min sessions, EMGBF alone</td>
<td>No treatment</td>
<td>Time to trace circle with olecranon</td>
<td>1.03</td>
</tr>
<tr>
<td>Inglis et al 1984</td>
<td>30</td>
<td>CVA &gt; 60 mo old, tested for aphasia</td>
<td>20 treatments, 3/wk, 1 hr sessions, PT + EMGBF</td>
<td>20 treatments, 3/wk, 1 hr sessions, PT only</td>
<td>Improvement in Brunnstrom’s stages of recovery</td>
<td>0.90</td>
</tr>
<tr>
<td>Crow et al 1989</td>
<td>40</td>
<td>CVA 2-8 wk old, no global aphasia</td>
<td>30 treatments, daily, part of acute rehab, PT + EMGBF</td>
<td>30 treatments, daily, part of acute rehab, PT only, EMGBF setup</td>
<td>Upper Extremity Functional Test</td>
<td>0.39</td>
</tr>
<tr>
<td><strong>Lower extremity</strong></td>
<td></td>
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<tr>
<td>Basmajian et al 1975</td>
<td>20</td>
<td>CVA &gt; 3 mo old, able to ambulate, no receptive aphasia</td>
<td>15 treatments, 3/wk, 40 min sessions, gait training + EMGBF</td>
<td>15 treatments, 3/wk, 40 min sessions, PT only</td>
<td>Change in need for ambulation aids</td>
<td>1.19</td>
</tr>
<tr>
<td>Burnside et al 1982</td>
<td>22</td>
<td>CVA &gt; 3 mo old, minimal receptive aphasia</td>
<td>12 treatments, 2/wk, 15 min sessions, gait training + EMGBF</td>
<td>12 treatments, 2/wk, 15 min sessions, PT only, EMGBF setup</td>
<td>Gait cycle time</td>
<td>0.84</td>
</tr>
<tr>
<td>Wolf et al 1983</td>
<td>12</td>
<td>CVA &gt; 1 yr old, able to ambulate, no receptive aphasia</td>
<td>30 treatments, 2-3/wk, 45 min sessions, gait training + EMGBF</td>
<td>No treatment</td>
<td>Basmajan, 1975, gait analysis grading system as cited above</td>
<td>0.89</td>
</tr>
<tr>
<td>Cozen et al 1988</td>
<td>16</td>
<td>CVA from acute, able to ambulate, min receptive aphasia</td>
<td>18 treatments, 3/wk, 30 min sessions, gait training + EMGBF</td>
<td>18 treatments 3/wk, 30 min sessions, PT only</td>
<td>Brainstem, 1975, gait analysis grading system as cited above</td>
<td>0.75</td>
</tr>
</tbody>
</table>

* Cerebrovascular accident.
† Biofeedback.
‡ Physical therapy.
§ Electromyography with biofeedback.
¶ EMG wires placed but no biofeedback given.
** Upper Extremity Functional Test.
†† Action Research Armtest.
A second criticism of meta-analysis suggests that by using published research the analysis is biased in favor of significant findings, because studies with nonsignificant findings are unlikely to be published. We attempted to deal with this problem by estimating the number of unpublished studies with nonsignificant findings needed to change the present results. The results suggested that it is unlikely that the file drawer effect has distorted the results.

A third criticism of meta-analysis proposes that results of meta-analyses are misleading because results from excellently conducted studies and poorly conducted studies are included together. The study's effect size may not be consistent with the quality of the research. Although researchers can deal with this problem by subjectively rating the quality of the included studies and controlling for the quality statistically, we believe that the use of studies appearing in peer-reviewed journals should act as a quality controlling factor.

Another limitation of the present study is a function of the relatively small number of publications that met the selection criteria. Although our search of the literature produced a variety of sources focusing on EMG-BF, we identified relatively few original research studies with appropriate design or outcome measures for inclusion in the meta-analysis. With more studies, confidence in the results increases. In our comprehensive review of the published literature, we applied stringent selection criteria to ensure appropriate scientific rigor. Thus, although many studies were not amenable to analysis, the stringency with which the studies were assessed before inclusion allows for confidence in the results.

In sum, EMG-BF appears to be a useful therapy for hemiplegic stroke patients and should be included in the therapeutic regimen.

References

APPENDIX

Included Studies