EEG amplitude neurofeedback: a review of the research

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Abstract

Studies published on neuromodulation for the past 50 years were analyzed for neuromodulation technique, research design, condition or disorder investigated and outcome. 314 relevant studies were found, involving over 9,500 research subjects. EEG amplitude neurofeedback contributed over 70% of all studies. 62 randomized controlled design studies were found (and two utilizing an ABA crossover design), and of those, over 75% involved amplitude neurofeedback. Outcomes for amplitude neurofeedback were overwhelmingly positive, as they also were for other techniques with a reasonable research base. For some neuromodulation techniques the research data is meagre, and more research is needed to confirm efficacy.

Keywords: EEG; amplitude; neurofeedback; neurotherapy; neuromodulation; review; research; study; modality; comparison; RCT; case

ARTICLE INFO		** Corresponding author.*
RECEIVED	November 18	E-mail address: info@neurotherapy.com.au
REVIEWED	January 19	
ACCEPTED	February 19	

1. Introduction

Over the past 10 years much has been made of new and innovative neuromodulation methodologies, with claims of efficacy exceeding that of the traditional mainstay of the neuromodulation field, single or double channel EEG amplitude neurofeedback training (henceforth referred to as amplitude neurofeedback or simply amplitude). While this can be seen as a marketing strategy, it nevertheless raises the question as a matter of science. Does evidence exist that amplitude neurofeedback is inferior to more recent neuromodulation methodologies? If so, are there particular conditions or disorders that respond more favorably to more recently developed methodologies (such as Slow Cortical Potential training, LENS training, 19-channel training and stimulation techniques)? In order to address this question, the literature on neuromodulation was reviewed. Of the research studies published, how many used amplitude neurofeedback as opposed to other modalities? What was the experimental design of the studies? What was the outcome of the studies? Is there still research being conducted on amplitude neurofeedback or has it been consigned to the museum of neuromodulation – figuratively speaking.

This review was first presented at the Applied Neuroscience Society of Australasia 2018 annual conference and was expanded and reformatted for journal publication. The project of collating and classifying neuromodulation research is planned to be an ongoing one, with the database of studies made available on an ongoing basis.

2. Methodology

a. Sourcing studies

The search for neuromodulation studies began at ISNR (International Society for Neurofeedback and Research) – reviewing their comprehensive bibliography - https://www.isnr.org/isnr-comprehensive-bibliography. Studies were classified according to publication year, neuromodulation technique, condition treated, study type/research design, number of subjects, and outcome.

ISNR's bibliography contains not only experimental studies, but also, studies on proof of concept – showing that a particular modality was having some effect on brain function, usually not directly clinically relevant. Additionally, the bibliography has references to books and book chapters as well as review studies (e.g. meta-analyses of several studies). Our interest was limited to experimental studies that were relevant to clinical outcomes for a condition/disorder or for peak performance training.

We expanded the search beyond ISNR's bibliography to include additional Slow Cortical Potential neurofeedback (SCP) and Low energy neurofeedback system (LENS) studies from the following websites:

- https://www.neurocaregroup.com/adhd-neurofeedback-and-sleep.html
- https://www.site.ochslabs.com/lens-references

As we searched further, we came upon additional articles, usually given from references at the end of previously found studies which we then sourced through PubMed:

- https://www.ncbi.nlm.nih.gov/pubmed

We then decided to search PubMed for neurofeedback studies from 2017 and 2018 (that were not already included) and added those as well.

We decided to only consider peer reviewed studies (i.e. studies that were published in a peer reviewed journal). When a study is peer reviewed, one has some assurance that the author of the study has employed at least a modicum of scientific rigor in the preparation of the study, that the outcomes reported seem reasonable and that the methodology is given in enough detail to allow replication.

We note that our search criteria may have had a negative bias towards including non-neurofeedback neuromodulation techniques. We plan on incorporating additional studies in future updates to this review.

b. Classification of studies - modality

For purposes of clarity, all amplitude neurofeedback modalities were grouped together. These included: Beta/SMR neurofeedback, Alpha neurofeedback, Alpha-Theta neurofeedback, Theta/beta ratio neurofeedback and other ratio trainings as well as one case study using Neuro Optimal methodology. Other modalities included Slow Cortical Potential neurofeedback (SCP); QEEG guided neurofeedback - where both amplitudes and coherences were trained (sometimes the term "QEEG-guided" was used to mean that results from a QEEG informed which amplitude neurofeedback protocols were used, in these cases the studies were classified as amplitude); Coherence neurofeedback; Low energy neurofeedback system (LENS) training; 19 channel Z-score training (including LORETA based training); Infra low frequency training; hemoencephalography (HEG) training and ffunctional magnetic resonance imaging (fMRI) neurofeedback. Stimulation methodologies included direct current stimulation (tDCS) and transcranial magnetic stimulation (rTMS) which were each given their own category, while the following stimulation methodologies were grouped together: Audio-visual entrainment (AVE), Roshi, Alpha stimulation, Photic stimulation, Vagus stimulation, and Neurofield magnetic stimulation.

We found two studies where two modalities were used, in direct comparison – head to head. These studies utilized a randomized control methodology (RCT) and compared SCP and amplitude neurofeedback. Both modalities were counted in our tallies as both studies found both modalities beneficial – see Table 3, Table 4 and Table 6.

There were also seven studies where two or more neuromodulation modalities were used in combination to treat subjects, (e.g. rTMS and amplitude neurofeedback). These were not counted for either modality as it could not be determined which modality drove the outcome of the study. It should be noted that all seven of these studies utilized amplitude neurofeedback as one of the methodologies. Whenever a study employed a neuromodulation modality in conjunction with another treatment or exercise which was not neuromodulation (e.g. another form of biofeedback or mindfulness meditation) then that study was counted for the single neuromodulation modality employed.

c. Classification of studies – study type / research design

We settled on four categories:

- Case study (1 – 3 cases).
- Case series, (more than 3 cases) with pre and post measures. Cherry-picking only positive outcome cases was not accepted. When it was not clear how many subjects were involved, a case series was classified as a case study.
- Control – some experimental controls, such as a waiting list control group, two groups – one clinical one non-clinical and/or partial randomization. Review of past records for somewhat matching clients who received different treatment was not accepted as a control group. Such studies were counted as case studies or series.
- RCT – Randomized Control Trial – contrasting two effective modalities, or a control condition considered efficacious by naïve subjects, all with random assignment to experimental or control groups, sometimes with cross over repeated measures with alternate treatments.
- Additionally, there were two studies which employed an ABA crossover design which we classified as RCTs as we took this study design to be of at least equivalent rigor to a RCT.

d. Classification of studies – outcome

This is a high-level study, so we simply classified outcomes as:

- Positive – researchers deemed results of the neuromodulation treatment to be positive, regardless of whether the effect was larger for a competing treatment (e.g. medication).
- Negative – researchers deemed results of the neuromodulation treatment to have no positive effect. It must be noted that some of these studies utilized training protocols that are contrary to accepted standard practice in the industry, e.g. reinforcing 18 Hz to treat epilepsy, or smaller numbers of training sessions.

e. Classification of studies – date

We classified studies into three time periods:

- 2009 – The present.
- 1999 – 2008.
- 1998 and earlier.

3. Results

690 articles were listed on ISNR's bibliography as of April 5, 2018 (see Table 1). There were 141 duplicate entries to the bibliography – studies belonging to more than one condition, and 4 double entries (i.e. same study for the same condition). For purposes of our analysis these studies are listed only in their first location – i.e. for only one condition or disorder. However, there were many studies in which we felt that they should be categorized differently (e.g. if subjects were selected due to presentation of a learning disorder, we changed the category to "Learning disorders" instead of "ADHD") and we changed the category as we saw appropriate. Of those left, 175 were book chapters, reviews, or theoretical papers. 77 studies were excluded as they did not involve treatment of a condition or peak performance training (or the measured outcomes were unknown or not directly linked to clinical improvement). Two studies were excluded as they were papers presented at a conference. The bibliography also contained 33 articles which could not be located, not even an abstract (27 of these studies were published prior to 1999 and six prior to 2009). This left 258 studies for review. Seven studies were added from the SCP and LENS websites and 49 studies were added from the PubMed search (see above and Table 2). This gave 314 studies in total. For 83 studies, only their abstract was found and reviewed. Also, there were two studies where two modalities (SCP and amplitude) were used in direct comparison – head to head (as noted above). In Table 3, Table 4 and Table 6 these studies were added to both modalities as both studies found both modalities beneficial, but they were not double counted in the totals (bottom row of the tables). For 17 studies, it was not completely clear which modality was used (often as the researchers just said "neurofeedback" in the abstract). For these we used our best judgement to determine which modality was studied (12 amplitude, three QEEG guided, one LENS and one Infra-low).

Table 1. Summary of ISNR studies

Total	Duplicates	Books, Reviews, Theoretical	No Treatment	Conference presentations	Not Found	Total Used
690	145	175	77	2	33	258

Table 2. Source of studies used

Source	Studies used	Abstract Only
ISNR	258	70
SCP	3	-
LENS	4	-
PubMed	49	13
Total	314	83

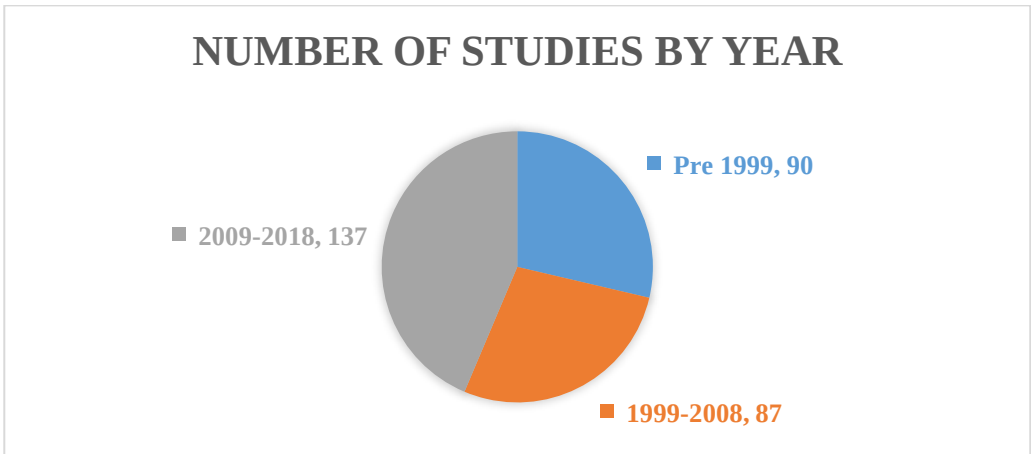

Fig. 1. Studies by year of publication

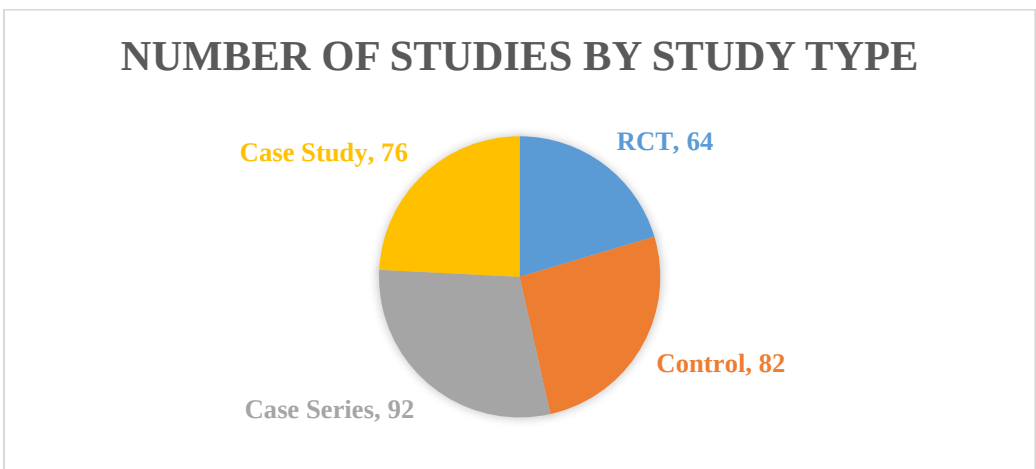

Fig. 2. Studies by study type

Figure 1 shows a breakdown of studies by time category. The trend is for studies in neuromodulation to be increasing. Figure 2 shows a breakdown into study types, with RCT studies comprising over 20% of published studies.

Table 3. Studies by modality

Modality	No. Studies	No. Successful
Amplitude (including head to head studies)	232	219
SCP (including head to head studies)	18	17
Stimulation	11	11
fMRI	8	8
LENS	7	6
HEG	7	7
QEEG guided	7	7
Z Score (19-channel including LORETA)	6	6
Coherence	5	4
Infra-low	3	3
rTMS	3	3
tDCS	2	2
Combined	7	7
Head to head	2	2
Total (does not include extra amplitude and SCP studies)	314	298

Table 3 shows a breakdown of studies by neuromodulation modality. Over 70% of all published studies used amplitude neurofeedback

Table 4. Studies by modality vs study type or research design

Modality	No. Studies	RCT	Control	Case Series	Case Study
Amplitude (including head to head studies)	232	50	64	62	56
SCP (including head to head studies)	18	5	6	7	-
Stimulation	11	1	2	4	4
fMRI	8	4	3	1	-
LENS	7	1	1	1	4
HEG	7	-	3	2	2
QEEG guided	7	-	-	6	1
Z Score (19-channel including LORETA)	6	-	-	4	2
Coherence	5	2	1	1	1
Infra-low	3	1	-	-	2
rTMS	3	-	1	2	-
tDCS	2	1	-	1	-
Combined	7	1	1	1	4
Head to head	2	2	-	-	-
Total (does not include extra amplitude and SCP studies)	314	64	82	92	76

When breaking down modality by research design, amplitude neurofeedback continues to account for the majority of studies in each category, reaching over 75% of all RCTs and control studies.

Table 5. Studies by condition treated

Condition	No. Studies	No. Studies with Positive Outcome	Modality Most Studied	No. Studies for Most Studied Modality
ADHD	82	78	Amplitude*	66†
Addiction (including alcohol)	21	20	Amplitude	19
Anger	2	2	Amplitude, LENS	1
Anxiety / Stress	13	11	Amplitude	11
ASD	18	18	Amplitude	13
Cognitive Decline	5	5	Amplitude	4
Depression	17	17	Amplitude	10
Dissociation	3	3	Amplitude	3
Epilepsy	35	32	Amplitude	26
Immune System (fibromyalgia and chronic fatigue)	6	6	Amplitude	4
Learning Disorders	15	15	Amplitude	11
Medical (Lyme's disease, angioedema, tinnitus, diabetes, and Chemotherapy Induced Neuropathic Symptoms)	7	7	Amplitude	6
OCD	4	4	Combined	2
Pain / headache	11	11	Amplitude	6
Parkinson's	4	3	Amplitude	2
Peak performance	26	25	Amplitude	20
Personality disorder	1	1	QEEG guided	1
Prison Inmates	3	3	Amplitude	3
PTSD	9	8	Amplitude	6
Schizophrenia	5	5	Amplitude	3
Sleep	5	4	Amplitude	4
Traumatic Brain Injury (TBI)	13	12	Amplitude	8
Tourette's	1	1	Amplitude	1
Stroke	8	7	Amplitude	4
Total	314	298	Amplitude	232†

*For ADHD, SCP studies are also impressive (see Table 6)

† These include the two head to head studies previously discussed.

Table 6. ADHD studies by modality and study type –head to head results have been added to amplitude and SCP results

Modality	RCT		Control		Case Series		Case Study		Total	
	Studies	Subjects	Studies	Subjects	Studies	Subjects	Studies	Subjects	Studies	Subjects
Amplitude	22	1,360	20	805	15	1,460	9	11	66	3,636
SCP	5	416	3	70	3	72	-	-	11	558
HEG	-	-	1	51	-	-	1	1	2	52
Stimulation	-	-	1	32	1	40	-	-	2	72
fMRI	1	31	1	13	-	-	-	-	2	44
Head to head	2	85	-	-	-	-	-	-	2	85
Combined	1	72	-	-	-	-	-	-	1	72
Total	27	1,794	26	971	19	1,572	10	12	82	4,349

Table 7. Epilepsy studies by modality and study type

Modality	RCT		Control		Case Series		Case Study		Total	
	Studies	Subjects	Studies	Subjects	Studies	Subjects	Studies	Subjects	Studies	Subjects
Amplitude	2	16	4	60	11	164	9	16	26	256
SCP	-	-	2	54	3	44	-	-	5	98
QEEG guided	-	-	-	-	1	25	-	-	1	25
Stimulation	-	-	-	-	1	7	-	-	1	7
Z score	-	-	-	-	1	6	-	-	1	6
Infra-low	-	-	-	-	-	-	1	3	1	3
Total	2	16	6	114	17	246	10	19	35	395

Table 8. Combined studies by modality and study type for anxiety, stress, depression and PTSD

Modality	RCT		Control		Case Series		Case Study		Total	
	Studies	Subjects	Studies	Subjects	Studies	Subjects	Studies	Subjects	Studies	Subjects
Amplitude	3	129	9	265	7	271	8	10	27	675
Stimulation	1	16	1	74	-	-	3	4	5	94
fMRI	3	110	-	-	-	-	-	-	3	110
LENS	1	17	-	-	1	7	-	-	2	24
Coherence	-	-	-	-	1	132	-	-	1	132
Infra-low	-	-	-	-	-	-	1	3	1	3
Total	8	272	10	339	9	410	12	17	39	1,038

In Table 6, Table 7 and Table 8 we introduce numbers of subjects to give a sense of the cumulative large numbers of subjects involved in the studies, adding validity to the positive outcomes reported. In total, over 9,500 subjects have been involved in neuromodulation research.

Both amplitude neurofeedback and SCP neurofeedback show very positive outcomes for ADHD (Table 6). In Table 8 we combined PTSD with disorders often associated with PTSD to give a perspective on a group of disorders not directly related to ADHD. In this smaller subset amplitude neurofeedback still plays a dominant role.

4. Discussion

EEG amplitude neurofeedback constitutes the vast majority of all neuromodulation studies, over 70%. This high percentage is ongoing. In 2018, of 26 studies reviewed, 19 involved amplitude neurofeedback, which is still greater than 70%. We only found and reviewed two head-to-head studies and these found that both amplitude neurofeedback and SCP neurofeedback were efficacious in the treatment of ADHD. We did not find evidence that one treatment modality is superior to any other for any of the conditions/disorders reviewed. However, for almost all conditions/disorders, amplitude neurofeedback had the most empirical support in terms of studies and numbers of subjects.

While it is beyond the scope of this review to analyze studies in depth regarding efficacy, several articles are of interest in this area (pro neurofeedback: Van Doren et al, 2018 and Piggott et al, 2018; against neurofeedback: Gelade et al, 2017 and Thibault & Raz, 2017). See also Coben, Hammond & Arns (2018) which takes issue with claims of efficacy of LORETA-based and Z-Score 19-channel training. Another interesting study explored improvements in functioning post neurofeedback training (Rance et al., 2018).

With neuromodulation methodologies diversifying, we need good studies so that we know which technique works best for which condition.

- We need case studies, especially for clients with unusual presentations.
- Where possible, case series give stronger support to a methodology, especially if the author is very specific on the "how to" component, which is critical to replicability. In clinical practice, if several practitioners, practicing independently validate a particular approach, with a particular client group, that is a very powerful endorsement. It is important to not cherry-pick cases that gave positive outcomes – to have unbiased selection criteria for which cases to include (e.g. all clients with particular characteristics seen between two dates). To not do so limits what can be learned from the case series as well as how much one can trust their findings.

- Clinic studies with controls eliminate some of the non-specific/unspecified elements (some say placebo) of the intervention as the cause of change. We need studies that are done with controls in a clinical setting for several reasons. Firstly, as clinicians, we do not seek to eliminate non-specific effects, we seek to maximize them. Furthermore, we do not randomly accept clients – they choose us, so the issue of random assignment to treatments is contrary to clinical practice. In addition, clients in clinic studies reflect real world conditions and comorbidities – the same as that which walks through our doors.
- RCTs are best for indicating the specific effect of a treatment. They are also needed to help gain mainstream recognition of neuromodulation.

Amplitude training still works, and still works well. It never didn't work well. In terms of research support, it is by far the strongest of the neuromodulation methodologies.

Regardless of which modality/form of neuromodulation practitioner's use, they are working to help their clients. Mutual support, rather than competitiveness and exclusivity will help the field grow. We look forward to a time when we know which neuromodulation methodology works best for which client group and which condition.

We plan on continually updating this review with additional studies (some that we were not yet able to locate, some that we have inadvertently excluded, and those that are yet to be published). We invite people to submit studies to be included in our database, and we aim to make the database we developed for this review available for general use.

5. Disclosures

The authors would like to disclose the following:

- Dr. Moshe Perl:
  - Has been practicing neurofeedback since 1998. He has predominantly used amplitude neurofeedback in his practice, and on occasion uses LENS. Additionally, he has studied and used a variety of coherence-based trainings including surface and LORETA 19-channel training.
  - Has been training and mentoring neurofeedback practitioners since 2001 in amplitude neurofeedback.
  - Has been a representative of EEG Education and Research (EEGer) (previously EEG Spectrum) for Australasia since 2001.
  - Is Board Certified in Neurofeedback by BCIA
  - Is a current member and past president of The Applied Neuroscience Society of Australasia (ANSA).
  - Is the director of the Neurotherapy Institute of Australasia (NIA)
- David Perl is a business manager of the Neurotherapy Institute of Australasia (NIA).

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