On the use of Event-Related Potentials as evaluation tools for the results of Speech-Language Therapy in patients with post-stroke aphasia: literature review

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ABSTRACT

The present study investigates the use and effectiveness of Event-Related Potentials (ERPs) as an evaluation tool for changes at the neurophysiological level in post-stroke aphasic patients' abilities resulting from Speech-Language Therapy (SLT). A literature review is carried out on Scopus and PubMed for the 2012-2022 period. Out of the 204 journal publications originally retrieved, 6 are selected according to a set of criteria. A major outcome is the consensus that ERPs reveal useful information on the topology of brain activity, brain plasticity and neural network reorganization of the brain at the various stages of therapy. Results of aphasia test batteries and ERPs do not always agree, however; this constitutes an argument for the use of ERPs as a complementary assessment tool besides test batteries. The limited number of relevant publications indicates the need for more research studies on this topic while analysis results point towards new directions for further research.

CCS CONCEPTS

• **Applied computing**; • **Life and medical sciences**; • **Human-centered computing**; • **Accessibility**;

KEYWORDS

post-stroke aphasia, event-related potentials, ERP, speech-language therapy, SLT, brain plasticity, neuroplasticity, review

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1 INTRODUCTION

Patients with post-stroke aphasia suffer language and communication problems that vary depending on the type and severity of aphasia. They receive Speech-Language Therapy (SLT) sessions to improve these abilities. Three types of tests are used to assess aphasia and SLT effectiveness: (i) comprehensive aphasia batteries, (ii) screening tests, and (iii) tests for the assessment of language and communication abilities, [1]. The results of such tests serve both diagnostic (type and severity of aphasia) and therapy-planning purposes. To achieve the same ends, Event-Related Potentials (ERPs) are being employed as an additional tool, at an experimental level.

This paper investigates the uses and effectiveness of Event-Related Potentials (ERPs) as evaluation tools for changes in the abilities as a result of Speech-Language Therapy (SLT). Aphasia is a dysfunction of the central nervous system with receptive and expressive components, manifested and results in language-level problems [2].

Speech-Language Therapy (SLT) sessions are delivered in order to improve language or communication abilities of the patient and increase his activities and participation [3]. Due to the heterogeneity of the aphasic population, SLT plans may vary regarding (i) the theoretical basis adopted by the experts, (ii) the target(s) of the specific treatment plan, and (iii) the SLT delivery media that may involve humans and/or technology. SLT can be personalized in terms of intensity, duration, and total amount to meet the patient's needs [4].

Event-related potentials (ERPs) refer to the recording and analysis of electrical waves produced by brain activity. They constitute a development out of the traditional electroencephalogram (EEG); both in EEG and in ERPs, electrodes are attached to the surface of the scalp in order to externally record the weak electrical signals produced by the brain. ERPs are the microvoltages generated in the brain in response to specific events or stimuli the individual is presented with. The electrical signals (waveforms) produced in response to such sensorial stimuli or motor stimuli or other cognitive events are time-locked to the respective stimuli. ERPs offer a non-invasive way to study the psycho-physiological manifestations of human mental processing. The signals recorded are considered representative of superimposed postsynaptic potentials that are produced when a large number of similarly oriented cortical pyramidal neurons fire in synchrony while the individual is mentally processing information, e.g., Blackwood & Muir, (1990) and Peterson et al. (1995), as referred in [5].

The methodology adopted here is that of a literature review. Only 6 publications meet the inclusion criteria. Their analysis is expected to reveal interesting facts as to the role and uses of ERPs in the above framework.

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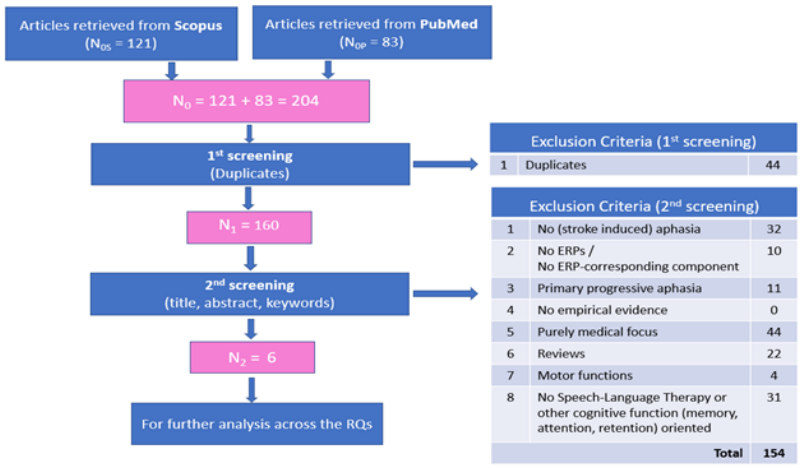

Figure 1: The selection process in steps.

2 REVIEW METHODOLOGY

The ultimate goal of this review is to aid in the formulation of an optimized protocol for the use of EPRs in the above context, based on recent research experience. To this end, the following Research Questions are posed:

- How frequent is the use of ERPs as an evaluation tool of SLT for post-stroke aphasia patients?
- Which research aims are reported in these publications?
- Which EPRs are used for language and speech disorders assessment?
- How long after the stroke has SLT started? How often were SLT sessions held? How long did SLT sessions last?
- What are the results obtained in the reviewed research studies?
- What are the open research questions identified in the reviewed research studies?

The literature review methodology adopted constitutes an adaptation of the PRISMA methodology. Search and retrieval of the original set of research publications has been performed in Scopus and PubMed. The query used for publication retrieval jointly employs

- the keywords: {“ERP” OR “Event-Related Potential” OR “Event Related Potential”} AND “Aphasia” in Scopus and {“ERP” OR “event-related potential” OR “event related potential”} AND “Aphasia” in PubMed,
- the inclusion criteria: {publication year: 2012-2022; publication type: journal; language: English}.

Figure 1 depicts the retrieval and selection process in PRISMA format. The initial set of publications includes N_0 = 204 articles (Scopus: 121, PubMed: 83). After excluding 44 duplicates, N_1 = 160 unique publications result from the 1st screening. The 2nd screening is performed on the basis of {title, abstract, keywords} and the exclusion criteria. 154 more articles are excluded and N_2 = 6 articles, identified as [A] - [F] and listed in the Appendix, are retained for full-text analysis.

3 RESULTS AND DISCUSSION

The considerable variability of the reviewed cases as to patient characteristics, disease and treatment data, aims and results is depicted in Table 1. The number of participants in the 6 reviewed studies are 4, 40, 10, 5, 1 and 9, respectively, with ages ranging in 28 – 83 years. The SLT sessions were conducted in Dutch, Russian, German and English languages. The types of aphasia of the patients are Wernicke and Broca, with the exception of [B], where the type of aphasia follows Luria’s proposal nomenclature. Aphasia severity of participants is classified as severe, moderate and mild per case.

3.1 RQ1: How frequent is the use of ERPs as an evaluation tool in recent research concerning SLT for post-stroke aphasia patients, as expressed by publications per year?

The use of ERPs in this context is rather infrequent. The exclusion criteria outlined in Figure 1 yield only 6 research studies in the last decade, published in years {2012, 2015, 2016, 2017, 2019, 2020} – possibly because aphasia test batteries are the standard for assessing aphasia types and SLT outcomes, as they offer a more manageable option compared to EPRs.

3.2 RQ2: Which research aims are reported in these publications?

SLT effectiveness for PWA is the major aim across the reviewed publications. Another aim is to assess the value of ERPs as diagnostic or verification tools on the recovery of PWA as a result of SLT. The major parameters or variables employed to fulfill these aims are the different clinical forms and severity of aphasia, the stages after stroke, as well as the SLT therapy ‘amount’, period, content and type. Behavioral and clinical measures of language ability have been used along with ERPs for the evaluation of SLT results. [B], [C] and [E] seek to establish SLT results and therapeutic effectiveness – whether SLT leads to improvements of linguistic skills. In [E], the

Table 1: Overview of the patient population in the reviewed studies.

Research Study	[A]	[B]	[C]	[D]	[E]	[F]
Number of participants (men / women / total)	4 / 0 / 4	18 / 22 / 40	7 / 3/ 10	2 / 3/ 5	1 / 0 / 1	8 / 1 / 9
Age (in years) (min / average / max)	46.6 / 60.9 / 71.4	(-) / 59.6 / (-)	32 / 51.2 / 73	46 / 58.6 / 83	47 / 47 / 47	28 / 52.2 / 62
Language used in the SLT sessions	Dutch	Russian	German	German	Dutch	English
Type of aphasia – severity (number of persons)	Wernicke - severe (4p)	Severe (18p); Moderate (20p); Mild (2p)	Broca-mild (4p); Broca-mild-to-moderate (2p); Broca-moderate (3p); Global-severe (1p)	Broca-mild-to-medium (1p); Broca-medium-to-severe (2p); Broca-severe (1p)	Non-fluent-moderate (1p)	Non-fluent (1p); Conduction (nonfluent) (1p); Anomic/apraxic (1p); Anomic (3p); Alexic/Anomic (1p); Expressive, Receptive, Apraxia (1p); Global (1p)

Table 2: ERPs used and tasks performed by the corresponding subject(s) across the 6 studies.

Research Study	ERPs used	Tasks performed by the corresponding subject(s)
[A]	MMN, P300	Auditory phoneme discrimination
[B]	MMN	Auditory phoneme discrimination
[C]	MMN	Syntactical / Lexical -semantical abilities
[D]	P300	Phonological abilities / Copy-spelling fixed words / Free spelling
[E]	*MMN*, P300, *N*400	Auditory phoneme discrimination / Auditory word recognition
[F]	N400	Lexical-semantic processing / Picture-name matching

overall SLT therapy period is broken down into blocks; the effectiveness of such period sub-division as well as possible influences of content, type and/or amount of therapy measures during the acute and post-acute phase after stroke are examined. [A], [C] and [F] are more focused on the uses and efficacy of specific ERPs. [A] investigates the value of the (pre-attentive) MisMatch Negativity (MMN) and the (attentive) P300 in the diagnosis and follow-up in an attempt to establish whether these ERPs are more sensitive than behaviorally sampled data. [C] focuses on *MMN* and its use either with well-formed and meaningful sentences or incorrect ones. [F] aims to establish whether N400 is sensitive to therapeutic change while [D] investigates the feasibility of Brain-Computer Interface (BCI) technology as a communication tool for PWA.

3.3 RQ3: Which EPRs are used for language and speech disorders (or for other cognitive functions)?

MMN, P300 and N400 are the ERPs used in the 6 reviewed studies (Table 2). MMN is used in [B] and [C], P300 is used in [D] and N400 is used in [F]. MMN and P300 are used in [A] while all 3 ERPs are used in [E].

3.4 RQ4: How long after the stroke has the SLT started? How often were SLT sessions held? How long did SLT sessions last?

The time interval between the onset of aphasia and the participation of the subject to the research study and the SLT provided therein (or the initial evaluation for participation) vary from 1 week to 20 years. In [C], for example, intervals of 19.9 and of 20.4 years are reported; in the rest of the studies intervals range between a few weeks and 2 years. The overall SLT duration is between 4 and 30 weeks (average values) with 4 weeks being the mode ([B], [C] and [F]). The frequency of SLT sessions is also greatly varying (1 to 25 hours/week). When the overall SLT duration is longer, as in [A] and [D], the frequency is lower (1 h/week and 2.5 h/week, respectively) - non-intensive therapy plans. When the overall SLT duration is limited ([B], [C] or [F]), the hours/week are increased (10, 15 or 25, respectively) - intensive therapy plans. Research study [E] adopts an alternating plan of [intensive – non-intensive – intensive] weekly blocks.

3.5 RQ5: What are the results obtained in the reviewed research studies?

The general agreement that SLT is beneficial for PWA and that intensity significantly affects the results is a major outcome of

this review; it also establishes the importance of the question on SLT assessment tools. The same view is supported by results from behavioral and electrophysiological evaluation tests. [B] reports that the highest efficacy score of restorative SLT sessions was obtained in 70% of patients and mainly in those with severe aphasia. Moreover, it is argued that regression of aphasia depends on the intensity of the therapy (frequency and overall duration). [C] reports that "intensive SLT leads to improvements of linguistic skills in chronic aphasia patients". Improved behavioral and neurophysiological measures at the end of SLT is reported in [E]. In agreement with existing research [3], [6], [7], [F] reports that 6 out of the 9 cases showed clinically significant improvement on at least 1 of the clinical aspects tested. Only cases already performing at a very high level, above 90%, did not exhibit improvement. Concerning the evaluation of ERPs as monitoring tools, results show that an indicator for a good recovery of language abilities over time is the early presence of phonological P300. Phonological ERPs seem to be sensitive to subtle linguistic deficits that are not detected by the established behavioral measures, [A]. For chronic post-stroke aphasia, [B] stresses the potential of MMN to serve as a biomarker of language recovery and cortical reorganization. The indicative value of MMN remains to be confirmed, however, [A]. In [C], significantly higher MMN amplitudes have been observed in both brain hemispheres in response to grammatically correct sentences, with the left hemisphere producing more pronounced changes. Plasticity effects, in terms of neuronal localization and modulation, are identifiable by neurophysiological measures as opposed to behavioral test alone, [E]. In [F], authors conclude that since the distribution of the N400 after therapy differs from that of healthy controls, it reflects the engagement of compensatory neural mechanisms. In [D] the aim is to investigate whether aphasic participants who fulfil the exclusion criteria for BCI use, can be trained to use a visual P300 speller.

3.6 RQ6: What are the open research questions identified in this publication?

Open research issues or questions are pointed out in all 6 reviewed studies. In [A], it is stated that the indicative value of a phonological MMN in the (sub)acute stage regarding recovery needs to be confirmed and that more behavioral language tasks are needed in order to be compared with phonological ERP values. [B] concludes (i) that (ab)normal ERP parameters should be evaluated before implementation in clinical practice, (ii) that the duration of courses of intensive speech therapy and the number of sessions per week remains under research, and (iii) that further research is required as to the classes of patients (stage, severity, clinical form of aphasia). [C] proposes to investigate (i) the neurodynamics of pseudowords and (ii) whether a slight reduction in intensity together with an extension of the therapy interval constitute a more effective plan. [D] proposes to investigate adjustments to user requirements while [E] proposes continued follow-up to identify further neurophysiological evolution. [F] focuses on whether the N400 of PWA is sensitive to therapeutic change arising from an intensive rehabilitative intervention.

4 CONCLUSIONS-FURTHER RESEARCH

The results highlight the need for further research, mainly because of the limited relevant studies and sample sizes. In contrast to aphasia test batteries, ERPs are language-independent tools. Aphasia test batteries and ERPs do not convey the same information; they are complementary rather than overlapping. Indeed, ERP-based evaluation results do not always agree to those of aphasia test batteries. Both tools should therefore be used and jointly evaluated. Accurate monitoring of information on brain plasticity and activity localization, as well as on neural network reorganization in the subject's brain along the sequence of phases of SLT, is critical for therapy planning. The additional contribution of ERPs is a detailed, measurable and accurate picture of brain topology changes. These results may confirm aphasia test batteries findings. On the basis of such data, a better and more personalized SLT planning is possible.

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REFERENCES

[1] Patterson, J. P. (2017). Aphasia Tests. In: Kreutzer, J., DeLuca, J., Caplan, B. (eds) Encyclopedia of Clinical Neuropsychology. Springer, Cham. https://doi.org/10.1007/978-3-319-56782-2_860-3

[2] Papathanasiou, I., & Coppens, P. (2013). Aphasia and Related Neurogenic Communication Disorders. Jones & Bartlett Learning.

[3] Brady, M. C., Kelly, H., Godwin, J. E., Enderby, P., & Campbell, P. (2016). Speech and language therapy for aphasia following stroke. Cochrane Database of Systematic Reviews, 2016(6). https://doi.org/10.1002/14651858.cd000425.pub4

[4] Brady, M. C., Ali, M., VandenBerg, K., Williams, L. S., . . . Wright, H. H. (2019). RELEASE: a protocol for a systematic review based, individual participant data, meta- and network meta-analysis, of complex speech-language therapy interventions for stroke-related aphasia. Aphasiology, 34(2), 137–157. https://doi.org/10.1080/02687038.2019.1643003

[5] Sur, S., & Sinha, V. K. (2009). Event-related potential: An overview. Industrial Psychiatry Journal, 18(1), 70. https://doi.org/10.4103/0972-6748.57865

[6] Choi, Y. Y., Park, H., & Paik, N. (2016). A Telerehabilitation Approach for Chronic Aphasia Following Stroke. Telemedicine Journal and E-Health, 22(5), 434–440. https://doi.org/10.1089/tmj.2015.0138

[7] Stahl, B. E., Mohr, B., Büscher, V., Dreyer, F. R., Lucchese, G., & Pulvermüller, F. (2018). Efficacy of intensive aphasia therapy in patients with chronic stroke: a randomised controlled trial. Journal of Neurology, Neurosurgery, and Psychiatry, 89(6), 586–592. https://doi.org/10.1136/jnnp-2017-315962

A APPENDIX: REVIEWED PUBLICATIONS

[A] Cocquyt, E., Knockaert, N., Van Mierlo, P., Szmalec, A., Duyck, W., Santens, P., & De Letter, M. (2021). The phonological Mismatch Negativity and P300 as diagnostic tools in stroke-related aphasia recovery: a longitudinal multiple case study. Aphasiology, 35(10), 1263–1280. https://doi.org/10.1080/02687038.2020.1787946

[B] Shklovskij, V. M., Alferova, V. V., Ivanova, E. G., Mayorova, L. A., Petrushevsky, A. G., Ivanov, G. V., Kuptsova, S. V., Kondrateva, E. A., & Guekht, A. (2019). Regression of Poststroke Aphasia and Concomitant Nonspeech Syndromes Due to Courses of Restorative Therapy Including Intensive Speech Therapy. Neuroscience and Behavioral Physiology. https://doi.org/10.1007/s11055-019-00856-3

[C] Lucchese, G., Pulvermüller, F., Stahl, B. E., Dreyer, F. R., & Mohr, B. (2017). Therapy-Induced Neuroplasticity of Language in Chronic Post Stroke Aphasia: A Mismatch Negativity Study of (A)Grammatical and Meaningful/less Mini-Constructions. Frontiers in Human Neuroscience, 10. https://doi.org/10.3389/fnhum.2016.00669

[D] Kleih, S. C., Gottschalt, L., Teichlein, E., & Weilbach, F. X. (2016). Toward a P300 Based Brain-Computer Interface for Aphasia Rehabilitation after Stroke: Presentation of Theoretical Considerations and a Pilot Feasibility Study. Frontiers in Human Neuroscience, 10. https://doi.org/10.3389/fnhum.2016.00547

[E] Aerts, A., Batens, K., Santens, P., Van Mierlo, P., Huysman, E., Hartsuiker, R. J., Hemelsoet, D., Duyck, W., Raedt, R., Van Roost, D., & De Letter, M. (2015). Aphasia therapy early after stroke: behavioural and neurophysiological changes in the acute and post-acute phases. Aphasiology, 29(7), 845–871. https://doi.org/10.1080/02687038.2014.996520

[F] Wilson, K. R., O'Rourke, H. P., Wozniak, L. A., Kostopoulos, E., Marchand, Y., & Newman, A. M. (2012). Changes in N400 topography following intensive speech language therapy for individuals with aphasia. Brain and Language, 123(2), 94–103. https://doi.org/10.1016/j.bandl.2012.06.005