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Training in rapid auditory processing ameliorates auditory comprehension in aphasic patients: A randomized controlled pilot study

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ABSTRACT

Experimental studies have often reported close associations between rapid auditory processing and language competency. The present study was aimed at improving auditory comprehension in aphasic patients following specific training in the perception of temporal order (TO) of events.

We tested 18 aphasic patients showing both comprehension and TO perception deficits. Auditory comprehension was assessed by the Token Test, phonemic awareness and Voice-Onset-Time Test. The TO perception was assessed using auditory Temporal-Order-Threshold, defined as the shortest interval between two consecutive stimuli, necessary to report correctly their *before–after* relation. Aphasic patients participated in eight 45-minute sessions of either specific *temporal training* (TT, n = 11) aimed to improve sequencing abilities, or control *non-temporal training* (NT, n = 7) focussed on volume discrimination.

The TT yielded improved TO perception; moreover, a transfer of improvement was observed from the time domain to the language domain, which was untrained during the training. The NT did not improve either the TO perception or comprehension in any language test.

These results are in agreement with previous literature studies which proved ameliorated language competency following the TT in language-learning-impaired or dyslexic children. Our results indicated for the first time such benefits also in aphasic patients.

1. Introduction

The relationship between rapid auditory processing (RAP) and language has been discussed for many years. Several studies indicated deficits in the processing of single units of language–phonemes (e.g., stop-consonants limited in time up to about 40 ms) due to RAP deficits. They resulted in deficient phonological awareness underlying receptive language deficits. These deficits have been often accompanied by disordered RAP in the time domain of some tens of milliseconds and reflected, for example, in auditory perception of temporal order (TO) of two stimuli presented in rapid succession. Using such a paradigm, auditory temporal-order-threshold (TOT) can be measured and defined as the shortest time gap between two consecutive stimuli which is necessary for a subject to report correctly their relation '*before–after*'. Some evidence indicated that for normal healthy volunteers this gap usually ranges from ca. 30 ms up to 80 ms [1–4]. Its duration is usually longer in elderly subjects than in younger ones, resulting in higher TOT values because of overlapping age-related declines in both timing and mental activity [5–8]. Elevated TOTs were also reported in patients with aphasia following left hemisphere brain lesions [9,2,10–12], children with language-learning-impairment [13,14] and children or adults with dyslexia [15,16]. Based on these data, some authors argued that proper processing of rapid temporal changes in the incoming speech signal is required for correct phonological processing [17].

Early studies by Efron [17] and Swisher & Hirsh [2] emphasized that timing deficits in aphasics were observed in ordering both auditory and visual stimuli (e.g. two diodes of different colours). This would suggest the existence of a central neural mechanism underlying the perception of TO, independent of the sensory modality. More recent studies confirmed significantly higher auditory TOTs in Wernicke's aphasics (about 120 ms) than in matched controls [9,10,12]. The close association between language and timing disorders was supported by neuroanatomical overlapping of structures involved in RAP and receptive language functions [9,10,12,18,19]. These structures comprised left

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hemispheric *gyrus temporalis superior*, *gyrus temporalis medius* and surrounding white matter.

Although many authors noted the overlapping between timing and language deficits [20–23], others doubt the existence of a cause–effect between these two functions [24–27].

In light of this evidence we should mention two important publications by Merzenich et al. [28] and Tallal et al. [29]. They reported amelioration of language functions following TIP training in language-learning-impaired children. These authors developed several training tasks in which three variables were adaptively adjusted to each subject's performance i.e., duration, frequency and inter-stimulus-interval in the presented stimuli. Four weeks of such intensive training resulted in significant improvement of RAP (i.e., TOTs lowered from 400 ms *pre-training* to 100 ms *post-training*) which was accompanied by improvements in phonological processing and auditory comprehension. These language functions remained untrained during the applied intervention [28,29].

Based on these reports, a training programme Fast ForWord (FFW) was developed by Scientific Learning (http://www.scilearn.com) and broadly implemented into clinical practice [30]. FFW was also applied in children and adults with dyslexia, bringing positive therapeutic effects. Nevertheless, some authors did not confirm any positive effects of FFW on writing, reading or spelling [30, for a recent review].

Despite existing evidence on clinical benefits of temporal training in language-disordered children, data indicating positive effects of temporal training in aphasic sample are very limited. The only early report by v. Steinbüchel et al. [31] demonstrated slight improvement in both auditory perception of TO and phoneme discrimination in aphasic patients following training in temporal discrimination. Their training procedure comprised 4 or 8 h of training in TO perception and a verbal feedback was provided on the correctness achieved. However, detailed information on the number of tested aphasics, description of the patient sample, temporal and control training parameters were missing from this preliminary report. To the best of our knowledge, there are no more reports on the application of temporal training in aphasic patients.

It should be mentioned that aphasia constitutes a major medical and social problem in modern society. As estimated by the demographic data, up to 270,000 patients with stroke-related aphasia are diagnosed worldwide each year [32]. Only a minority of them recover completely from their language deficits. Examinations of typical recovery curves revealed that only 25% of patients have a chance for the full restoration of disturbed language. It indicates the importance of implementation of new techniques of rehabilitation to change the burden of language-disordered individuals with the adoption of new intervention based on neuronal mechanisms underlying language.

Considering the importance of RAP in language, in the present study we tested whether timing deficits in aphasics could be reduced by the specific acoustic training in RAP. Furthermore, we investigated whether a transfer of improvement could be observed from the trained time domain to the language domain which was untrained at that time. Taking into account the number of aphasic patients, such a new therapeutic approach could be applied in neurorehabilitation programmes targeting aphasic patients. This study offers some important scientific indications for new components of therapy programmes.

2. Methods

2.1. Participants

Eighteen patients (9 male and 9 female) suffering from aphasia after first-ever stroke (haemorrhage or infarction, lesion age $\bar{x} \pm SD = 17 \pm 11$ weeks) participated in the study. They varied in age from 34 to 76 years ($\bar{x} \pm SD = 55.4 \pm 11.2$ years), were right-handed [33], Polish native speakers and had normal hearing level verified by screening audiometry (audiometer AS 208), using frequencies of 250, 500, 750, 1000, 1500, 2000 and 3000 Hz [34]. Apart from stroke they had neither neurological nor psychiatric disorders and reported no history of head injuries. Description of the patient sample is given in Table 1.

All patients displayed auditory comprehension deficits evidenced by the Token Test [35]; Phoneme Discrimination Test (PDT) [36] and Voice-Onset-Time (VOT) Test [37]. Their language deficits were accompanied by disordered RAP (for detailed description see below). We adopted the following exclusion criteria: recurrent stroke, global aphasia with poor verbal contact, poor general health, participation in other rehabilitation programmes during our study, and older age to minimize undiagnosed cognitive deficits which might have negative effects on the training results. These inclusion/exclusion criteria allowed to diminish the risk uncontrolled side-effects which could influence the experimental verification of therapy effectiveness. But such therapy is addressed in future broader patients population suffering from also other language disorders.

It was a blinded randomized controlled study. The patients were randomly assigned into two groups according to age, gender, lesion age, level of comprehension deficits and RAP deficits (Tables 1–3). The first group was assigned to temporal training (TT, n = 11) and the second one to nontemporal control training (NT, n = 7). For detailed description of the training protocols see below. Evidence has suggested that the above mentioned subject-related factors generate vulnerability with respect to restoration of language and aphasia rehabilitation. Synopsis of pre- (white column) and post-training (grey column) performance profile in each individual subject is given in Tables 2 and 3.

Using *U* Mann–Whitney test, all pre-training between-group differences for all these variables were nonsignificant, i.e., for age: $z = -1{,}09$, $p < .28$; lesion age: $z = 0.18$, $p < .86$; RAP assessed by TOT: $z = 0.45$, $p < .66$, comprehension level assessed by the Token test: $z = -0.58$, $p < .57$; PDT $z = 0.73$, $p < .45$ (Table 2), VOT $z = -0.14$, $p < .90$. It indicated a balance between TT and NT groups (Tables 2 and 3), allowing the comparison of the effectiveness of two different training procedures in groups with relatively similar subject-related characteristics, as well as pre-training performance, thus, similar prognosis for language recovery.

The place of the lesion was evidenced by CT or MRI. Fig. 1 presents the summarized damaged regions in TT and NT groups. Neuroanatomical analyses confirmed that in both groups lesions were localized mainly in the left hemispheric temporal lobe and covered the classical areas engaged in both auditory comprehension and time perception [10,12,38,39]. In particular, in the TT group lesioned areas comprised *superior temporal gyrus*, *Heschl's gyrus*, Rolandic *operculum* and *insula*. Almost exactly the same areas were damaged in the NT group: *superior* and *middle temporal gyrus*, *Heschl's gyrus*, *Rolandic operculum, insula, putamen* and *frontal inferior orbital lobe*.

Furthermore, the synopsis of brain damaged regions in individual patients assigned to TT and NT is documented in Fig. 2. Considering individual patients' data evidenced in Tables 1–3 and Fig. 2 it may be assumed that the TT and NT groups were as matched as possible.

2.2. Ethical approval

The research was approved by the Bioethics Commission at the Institute of Psychiatry and Neurology in Warsaw (permission no 5/2005 from February 2nd 2005) as well as by the Bioethics Commission at the Warsaw Medical University (permission no 5/2010 from January 26th 2010). The study was conducted according to the principles expressed in the *Helsinki Declaration*; the written informed consent from each participant was obtained prior to testing.

2.3. Procedures

The study comprised both *assessment* and *training procedures*. The *assessment procedures* included TOT measurement, language and attention tests which were performed *before* (pre-training assessment) and *after* the training (post-training assessment). Moreover, the *follow-up*