Keeping the Brain's Clock Ticking

ELŻBIETA SZELĄG
Laboratory of Neuropsychology, Nencki Institute of Experimental Biology
Polish Academy of Sciences, Warsaw
Faculty of Neurorehabilitation, University of Social Sciences and Humanities, Warsaw
e.szelag@nencki.gov.pl
Prof. Elżbieta Szeląg studies the neuropsychological mechanisms underlying human cognitive function - in particular, the perception of time and temporal dynamics of information processing.

Time perception is a key function of the human mind. Its disruption can lead to difficulties in many areas of our cognition, including language communication. Our research has managed to repair damaged "neural clocks" in people who have difficulties in language communication

Planning and carrying out movements, making decisions, paying attention, learning new information, accessing memories, and - of course - using language: all these cognitive functions are rooted in "prelingual" neuronal mechanisms that shape the functioning of neural pathways and are characterized by specific dynamics. Intervals measured in milliseconds form a neural pattern (matrix) used by the brain to process information. This pattern can become deficient following damage to the brain, or as a result of neurodegenerative disorders in adults and neurodevelopmental problems in children.

Key milliseconds

A number of stimuli that are constantly being received by the human brain - frequently in rapid succession - are processed sequentially, since analyzing them concurrently would likely overload the neural network. This is what makes integrative mechanisms so important, since they merge together individual events occurring within specific, precisely defined time windows. The brain is able to distinguish between two individual stimuli as long as they are separated by intervals of at least 40 milliseconds. This fact is key to linguistic communication. As it turns out, the shortest phonemes (stop consonants such as t, d, k, g, p and b) tend to be around 40 milliseconds long in many natural languages. In natural speech, there is no way of extending their duration, instead we can only prolong the vowels that commonly follow them. This brevity of stop consonants makes them difficult to differentiate for people who have problems with temporal processing of information. Patients suffering from a disordered temporal matrix frequently struggle with minimal pairs, such as "Tim - dim" and "pan - ban". They generally have fewer problems with fricative consonants (s, z, v, f) and vowels, which in natural speech can extend as long as 200 milliseconds.

Aside from this millisecond-scale clock, human behavior is also affected by mechanisms working on longer timescales of up to a few seconds. This is the rhythm behind the formation of logical strings of words (phrases). For an utterance to be understood correctly, groups of words must be followed by pauses long enough for the listener to process the information, and for the speaker to formulate the next phrase. Interestingly enough, this several-second rhythm does not depend on the language in which the phrases are formed - the same rhythm characterizes languages as diverse as Polish, German and English, as well as tonal languages such as Chinese. The pattern of a few seconds is also noticeable in gestures; it is roughly the time taken to deliver a greeting by waving, nodding the head, or shaking someone's hand. A handshake that lasts any longer or shorter will be perceived as significant, oppressive or unpleasant, since it falls outside the typical time frameworks in which the brain operates. Speech and movement are controlled by a similar neural program, resulting from their neuroanatomical representation - sensory and motor areas responsible for both body and articulatory movements are located near one another, in the primary motor cortex in the frontal lobe. This proximity means that speech therapy frequently brings best results if it is augmented with hand exercises.

Sign languages follow similar temporal segmentation patterns to spoken languages; deaf children acquiring a sign language as their native language go through similar stages of development to their hearing peers. The difference stems simply from the modality used to communicate - hand movements or the use of the speech organs, respectively.

Jakub Ostałowski

Many patients are helped by classical speech therapy. But if it does not produce the desired results, in spite of correct exercises and good motivation of the patient, the next stage is to consider treating the function of the neural network. Photo shows a therapy session held at Primary School No. 212 in Warsaw

Neural players

The temporal mechanisms controlling linguistic communication have been extensively studied by Ernst Pöppel, a world-renowned brain scholar, neuropsychologist and neurophysiologist from the Human Science Centre at the University of Munich; for many years, he has been collaborating with the Laboratory of Neuropsychology at the PAS Nencki Institute of Experimental Biology to investigate the neural basis of speech disorders. His theories have had applications in clinical practice for almost 20 years. Michael Merzenich from the University of California (San Francisco) and Paula Tallal from the University of California (San Diego), published a pioneering paper in Science in 1996, documenting the positive effects of therapy based on retuning the brain "clock" in children with delayed speech. Their research initially involved exercises in which children passively listened to computer-processed speech that was slowed down, down even to half the speed at which words are usually spoken. Additionally, the recordings emphasized stop consonants, acoustically more difficult to perceive, to make them more distinct. The program brought impressive results: after just four weeks of therapy, the participating children's own speech showed a marked improvement. The software was soon expanded into a full version known as Fast ForWord, which is now a recognized therapeutic tool in the US.

The program includes several computer games featuring sounds made by animals, extraterrestrials, machines, and so on. Depending on the exercise, the child's task is to indicate the source of the sound, respond to its start, duration or end, and arrange the sounds in the right order. Correct answers are awarded points, and after completing a set of exercises the user moves on to the next level, featuring new sounds which are more difficult to distinguish and which arrive in more rapid succession.

However, despite the popularity of Fast ForWord in American schools and clinics, academic society continues to debate its effectiveness. One of the key shortcomings of the program lies in the difficulty of creating non-English versions adapted to different languages and cultures; for example, in Poland we are only able to use a small, non-verbal part of the full program. Additionally, all the exercises focus on perception in the millisecond range, neglecting other key time intervals also essential for cognitive functioning. Finally, Fast ForWord does not include a diagnostic module that could be used, prior to purchase,

to assess whether a patient does in fact exhibit symptoms of a deficiency of temporal processing, or would instead benefit more from classical speech therapy.

Finding the right word

The Laboratory of Neuropsychology at the PAS Nencki Institute of Experimental Biology is involved in research on improving human cognition, focusing in particular on linguistic competence. A few years ago, we started working on a therapeutic program adapted to the specificity of the Polish language. It comprises exercises aiming to improve the temporal dynamics of information processing, as well as several tasks enhancing general cognitive function not linked with language.

The first, experimental version of the program was aimed at adult patients exhibiting symptoms of aphasia – a loss of language competence following stroke. Some patients do not understand what is said to them, while others struggle with expressing themselves fluently, and as a result tend to limit themselves to single-word utterances. Stil others find it difficult to find the correct word; for example, when looking at a teacup, they may describe it as "a small round thing with a handle". Some patients' problems stem from damage to the neuronal network controlling the temporal processing of information. The aim of our exercises, therefore, is to train the neural matrix that forms the basis of language perception. Patients have shown improvement in their temporal perception, as well as showing positive results in other, non-exercised language domains and non-linguistic cognitive function (Szelag, Lewandowska, Wolak, Seniow, Poniatowska, Pöppel & Szymaszek, 2014).

Not just language

Elderly people frequently report problems with short-term memory and learning new information, and experience difficulties concentrating, making decisions, forward planning, and so on. According to classical theories, age-related problems are irreversible, since they are linked to (or result from) neurodegenerative changes in neural networks. However, more recent research suggests that certain exercises can help restore some lost functions through neuroplastic changes, which are still possible.

Our groundbreaking research demonstrates the effectiveness of therapies focusing on temporal training in elderly people exhibiting cognitive deficiencies that are not due to damage sustained to the nervous system or neurodegenerative diseases (Szelag & Skolimowska, 2012). Our results have been recognized by the scientific community, and our publication was named "paper of the year 2012" by the Editor-in-Chief of the journal Restorative Neurology and Neuroscience.

We randomly classified volunteers aged 65-75 into three groups. The first group took part in exercises using software aiming to improve the temporal dynamics of their information processing, the second played traditional computer games lacking a temporal aspect, while the third did not participate in any form of training. We compared cognitive function in all groups and the subjects' efficiency at temporal processing of temporal information before and after taking part in the exercises. Only the first group showed a significant improvement in information processing, memory, and attention. In the second group, we observed an improvement in sound recognition, whereas the third one showed no change. Follow-up studies demonstrated that the positive results seen in the first group were still maintained 18 months after the end of the training.

Jakub Ostałowski

A Polish speech therapy program is being funded by an INMET grant from the Polish National Centre for Research and Development. Its effectiveness is being evaluated as a part of the scientific partnership with the Early Intervention Centre, directed by Monika Kastory-Bronowska, and the Geriatric Clinic at the Medical University of Warsaw, led by Prof. Krzysztof Galus, as well as Universities of the Third Age. Our commercial partner is the company HARO (Poznań). Following validation and commercialization phases, the software will be made available to individual users and clinics, under inexpensive licenses. Users will be able to access the software from PCs, laptops and tablets. The research has also been funded as a part of the Polish-German grant no. 507/1/N-DFG/2009/0, and the grant INNOTECH-K1/IN1/30/159041/NCBR/12 from the Polish National Centre for Research and Development

Patience isn't always a virtue

Disorders of linguistic communication affect approx. 30% children around the world. In this age group, we focus on delayed development of speech and language. In many children, motor and intellectual development proceed normally, whereas only language abilities are selectively affected (known as Specific Language Learning Impairment, F80, ICD10), which can be treated fairly simply with regular speech therapy. However, speech delay is persistent

in some children in spite of intensive rehabilitation. The difficulties in treating such disorders stem, in part, from the existence of critical periods in the development of speech; if these periods are exceeded, in certain cases the child may never achieve full linguistic ability. Physicians frequently wrongly reassure parents and recommend patience when their three-year-old is only able to say a few words. In such situations, it is easy to miss a point critical in the development of speech, linked with a rapid development of neural networks. Children who – in spite of normal intellectual development – do not start using full sentences until they are eight or older will never become fluent users of their native language.

Developmental delays in speech do not have a single specific cause, and language problems may arise for a number of different reasons. The most common include disorders purely affecting the language domain, although prelingual problems are equally common. The defect is generally not caused by brain damage, but by a functional deficiency involving the neural network processing information incorrectly. Such disorders, rooted in deficient temporal perception, are pernicious and difficult to treat; in some children, they may present alongside problems in distinguishing frequencies of sounds produced during speech. Our therapeutic program has been designed with these patients in mind.

Fitter brains for all

As well as helping children and elderly people, our exercise programs have been shown to produce improvements in healthy, young volunteers. Their training program was intensive, with four hour-long sessions per week over the course of eight weeks. At the end of the program, electrophysiological studies and fMRI scans detected changes in the standard of information processing at electrophysiological and neuroanatomical levels. Additionally, these results have been shown to be enduring.

Overall, therapies modifying the function of the neural clock have been producing very promising results so far. Such techniques may well turn out to be the future of rehabilitation, as well as being useful in improving our learning skills, attention, working memory and analytical processing. ■

Further reading:

Szeląg E., Lewandowska M., Wolak T., Seniów J., Poniatowska R., Pöppel E., Szymaszek A. (2014). Training in temporal information processing ameliorates auditory comprehension in aphasic patients: a randomized controlled pilot study. *Journal of the Neurological Sciences* (w druku).

Bao Y., Szymaszek A., Wang X., Oroń A., Pöppel E., Szeląg E. (2013). Temporal order perception of auditory stimuli is selectively modified by tonal and non-tonal language environments, *Cognition, 129*, 579-585.

Szeląg E., Skolimowska J. (2012). Cognitive function in elderly can be ameliorated by training in temporal information processing. *Restorative Neurology and Neuroscience 30*. 419–434.

Lewandowska M., Piątkowska-Janko E., Bogorodzki P., Wolak T., Szeląg E. (2010). Changes in fMRI BOLD response to increasing and decreasing task difficulty during auditory perception of temporal order. *Neurobiology of Learning and Memory 94*. 382-391.