Therapeutic training in post-stroke disturbances of vision

Trening terapeutyczny w poudarowych zaburzeniach wzrokowych

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Key words
stroke, hemianopia, recovery, rehabilitation

Abstract
Introduction: Vision disturbances are a frequent sequel of stroke. Damage to primary or secondary visual cortical areas can lead to chronic or temporary dysfunction of vision that hampers recovery from stroke. Nevertheless, they are rarely regarded as a prominent problem for neurorehabilitation.
Aim of the study: This paper presents a review of current knowledge on possible therapeutic interventions in one of the most frequent vision disturbances following vascular brain damage, i.e. visual field defects.
Study form: We reviewed data from the literature pertaining to theoretical background of various therapeutic approaches to vision disturbances as well as empirical evidence of the effectiveness of these approaches.
Conclusions: The analysed data suggest that improvement of visual function in post-stroke patients is possible with the help of a therapeutic training that uses preserved functions such as visual scanning or residual vision. The objectively observed training-induced improvement of visual field defects and of the related deficits is frequently reflected in a better performance during activities of daily-living.

Słowa kluczowe
udar mózgu, niedowidzenie połowicze, rehabilitacja

Streszczenie
Wstęp: Deficyty wzrokowe są częstym następstwem udaru mózgu. Uszkodzenie pierwotnych oraz drugorzędowych okolic wzrokowych może prowadzić do trwałych lub czasowych dysfunkcji widzenia, które opóźniają powrót do zdrowia. Mimo to, są one rzadko traktowane jako ważny problem w neurorehabilitacji.
Cel pracy: Przedstawienie aktualnej wiedzy na temat możliwości terapeutycznego oddziaływania w przypadku jednej z najczęstszych wzrokowych komplikacji po naczyniowym uszkodzeniu mózgu tzn. w zaburzeniach pola widzenia.
Projekt pracy: Przeanalizowane zostały dane z literatury dotyczące przesłanek teoretycznych różnego typu interwencji rehabilitacyjnych oraz empirycznych dowodów na ich efektywność.
Wnioski: Zebrane dane wskazują na możliwość poprawy funkcji wzrokowych u pacjentów po udarze mózgu w wyniku specjalistycznego treningu wykorzystującego zachowane funkcje takie jak zdolność przeszukiwania pola spostrzeżeniowego oraz szczątkowa wrażliwość na bodźce wzrokowe. Obserwowane obiektywnie wycofywanie się zaburzeń pola widzenia oraz towarzyszących deficytów wzrokowych pod wpływem powtarzalnych ćwiczeń często przekłada się na lepsze funkcjonowanie chorych w życiu codziennym.

INTRODUCTION

Normal visual perception requires that multiple units of the visual system and processes occurring in this system are functionally preserved. Basic visual functions such as appropriate visual acuity, visual field, sensitivity to contrast, colour perception and capability of producing visual sensations are essential (although not sufficient) for normal vision. Thanks to these properties, it is possible to process visual information of higher-order complexity – differentiation of sizes and shapes of stimuli, localisation of those stimuli in space and storage of information about their position in relation to certain orientation points, as well as it is possible to recognise known pictures (on the perception level and the level of interpretation of meanings). Moreover, ability to actively (using the oculomotor system) scan the visual field constitutes an important part of visual perception. This motor aspect of

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perception enables humans effective functioning in the changing conditions of visual environment.

A great number of factors and conditions may, on one side, be associated with high probability of visual disturbances resulting from a dysfunction of even on of the above-mentioned elements, on the other side, however, there is evidence demonstrating a high compensation capability of possible abnormalities in the visual system.

It is estimated that 20 to 40% of post-stroke patients suffer from various types of disturbances in visual perception including deficits at both basic and higher – cognitive – level[1]. These deficits include: visual field defects, unilateral neglect syndrome (spatial attention defect), visual-spatial disturbances, disturbances in recognition of visual objects (visual association agnosia) and other, rarer syndromes. Dysfunctions of this type constitute factors negatively affecting the process of healing following stroke, which prolongs patients' hospitalisation[2,3] and compromises rehabilitation that primarily aims at achievement by the patients their independence in every-day life.

PLASTICITY OF THE VISUAL CEREBRAL CORTEX

A well-documented (in many interdisciplinary studies) and recognized phenomenon of functional reorganisation (neuroplasticity) is the principal theoretical prerequisite in the therapy of vision disturbances resulting from damage to the central nervous system. Not only is developing brain characterized by this capability but also (to a surprisingly great extent) mature nervous system does have this property[4,5]. Reorganisation is a spontaneously initiated process that occurs following damage to the brain (lesion-induced neuroplasticity) and is also an effect of human experience and activity and – taking the latter process into account – it is considered training-induced neuroplasticity.

A great part of knowledge on central nervous system plasticity emerged from studies on reorganisation of the somatosensory cortex[6], however, these phenomena were demonstrated in multiple brain regions. Accoridng to a similar scheme as in case of the sensory cortex, it was attempted to demonstrate formation of changes in functional patterns of the cortex following experimental deafferentation of the visual regions. Kaas et al.[7] documented modification of receptive fields in the primary visual cortex of adult cats resulting from damage to a part of the retina. Neuronal regions deprived of afferent impulsation were becoming, after several months, a part of other representations, corresponding to those regions of the retina that surrounded the site of the lesion. In another experiment on cats, performed by Gilbert and Wiesel[8], similar reorganisation was observed as early as several minutes after retinal damage. Neurones located in the centre of deafferented region not only enlarged their receptive fields but also these fields moved towards the border of the damaged region. Two months following retinal damage, all the neurones in the region formerly deprived of stimuli were again reacting to visual stimuli that now were originating in other regions of the retina. Other changes in receptive areas were also observed, such as consolidation, separation into two parts (the same neurone could respond to stimulation of isolated regions located on both sides of the primary – damaged – field) and „translocation" of representation (probably via the corpus callosum) to the other cerebral hemisphere. The authors of the mentioned studies share an opinion that changes occurring in cortical representations are primarily evoked thanks to horizontal connections among the neurones.

In the context of reparation of visual functioning following damage to the occipital lobes, information about activation of these brain regions during visual perception in healthy persons is of particular importance. Zeki et al.[9] demonstrated that activation initiated in the primary visual cortex spreads to neighbouring regions. Further, structural damage restricted to the V1 field leads to a decrease in glucose metabolism in a markedly greater area than that of the very damage. This was demonstrated by Bosley et al. by means of positron emission tomography (PET)[10]. As a result of those relatively disseminated functional changes, disturbances in processing of information occur even within structurally unchanged regions of the cerebral cortex also in the other, theoretically healthy, hemisphere[11].

HEMIANOPIA

Hemianopia is the most frequent post-stroke disturbance of the visual field resulting from a damage to the visual pathway behind the optic chiasm. As it contains fibres conveying impulses from the nasal part of one retina and temporal part of the other retina, a complete or partial loss of ability to perceive visual sensation from one side of the visual field occurs. Pambakian et al.[12] estimate that this type of vision disturbances is present in 30% of post-stroke inpatients. Similar prevalence was reported by Kerkhoff et al.[13] in a population of inpatients of a neuro-rehabilitation ward. Spontaneous recovery of visual function following damage located behind the optic chiasm (post-chiasmatic) is estimated for 12-30%[14]. Kerkhoff[15] observed an improvement in 15% of 225 patients with visual field defects that occurred within three months. Average size of the recovered visual field was 3 degrees. Unfortunately, after this period of time, spontaneous recovery of function was rare.

Apart from the visual field defect-type of vision disturbances, in the scholarly literature, attention is paid to the accompanying disturbances of scanning the visual perception field (especially during the first months of the disease). This disturbance pertains to scanning using both ocular movements[16-19] and head movements[13,20]. Patients also present various (depending on the side of hemianopia) patterns of reading disturbances[18]. An anlysis conducted by Zihl[21] showed that 60% of patients with hemianopia had an abnormal pattern of oculomotor activity during visual exploration of the visual field, characterised by a statistically greater number of fixations both in the „blind" and the „healthy" visual field. While patients with left-sided defect perform more (although at a reduced amplitude) movements to the right, eye movements of patients with right-sided defect are disorganised both during the typical scanning task and during reading[18]. Pambakian et al.[19] stress out that in the group of patients hemianopia, saccades („jumping" eye movements) that aim at a target that is independent of the picture in the visual field, dominate. Oculomotor pattern is more random than in case of healthy persons. Fixation times are shorter than in healthy persons, which is likely due to the lack of information from the peripheral regions of the visual field, essential for planning subsequent eye movements.

The fact that in clinical practice, the described deficits are not considered as requiring therapeutic intervention, may be due to an unjustified assumption that these abnormalities are spontaneously compensated for during every-day life. Refraining from therapeutic attempts is also being justified by the lack of subjective complaints of patients (while the not infrequent phenomenon of limited insight into neurological patient's deficits, i.e. anosognosia, should be kept in mind). Compensatory role of motor factors (movements of the head and eyes) in alleviation of disturbances in visual perception due to visual field defects has also been emphasized[16]. Despite this fact, attention is directed towards real problems of patients with visual field defects in natural, daily-life situations that are especially evident e.g. in persons working in jobs requiring immediate reactions on visual stimuli, during watching fast-changing images or when moving in a crowd. It is higher expectations of post-stroke patients as to restoration of their full comfort of life as well as increased demands of social environment (particularly in some types of jobs) that have probably caused a situation that in the last decades, this topic has more frequently been analysed in the scholarly literature, especially in association with rehabilitation treatment[13].

To continue the tradition of studies on restoration of visual function in post-stroke patients – initiated by Poppelreuter – a group of researchers (mostly German) attempted to create a rehabilitation therapy program for patients suffering from visual field defects. Among these attempts, the following two approaches can be outlined: an approach oriented towards behavioural compensatory mechanisms of permanent deficits[12,18-21] and visual training supposed to lead to restoration of the lost basic visual abilities in the region of visual field defect[13,22-25].

Compensatory training

Zihl's patients[21] were subjected to trainings of visual scanning in two stages. During the first stage, they performed exercises involving searching for a target – single light point presented in the region corresponding to visual field defect. In this situation, it was necessary to perform long-lasting saccades towards the blind spot so that one such movement would be sufficient to localize the stimulus. The participants were, therefore, asked to attempt to find the target by performing a single ocular movement to the appropriate direction. Five to six sessions with approximately 100 stimulus presentation were needed for the patients to learn to localize all stimuli without mistakes. Further stage involved exercises in scanning visual images consisting of configurations of various shapes presented on slides. The participants were taught a systematic method of scanning to localize visual stimuli characterized by given features. Shortening of time needed for effective scanning of the visual perception field was the outcome of the training (11 of 14 patients were found to perform within the normal range), which was associated with a smaller general number of fixations and their repetitions. Saccades recorded in the evaluated persons after termination of the training continued to have a significantly greater range.

Pambakian et al.[12] conducted a similar training of visual scanning in patients with hemianopia. Training sessions were carried out for 40 minutes daily for a period of one month. The patients had suffered brain damage at least 3 months before inclusion into the study (dynamic spontaneous improvement is no longer expected after such time). Despite the lack of significant changes in visual field itself, the authors managed to document a significant improvement as a result of the training. The improvement involved reaction time to stimuli located in the blind part of the visual field and an increase (by 4 degrees) in visual scanning field (defined as an area that could be scanned by a patient using eye movements only). In tasks that the authors prepared to measure the effects of training, involving taking advantage of the acquired abilities in every-day life (e.g. sorting real objects), the patients reacted after the therapy by 25% faster than before the treatment. Kerkhoff[15], by reviewing the effects of studies with use of scanning training, cites results demonstrating a broadening of scanning field by as much as 20-30 degrees and a 33% reduction of skipped items as well as a 25% increase in reaction time. Moreover, as a result of the training involving compensatory eye movements, a partial restoration of the visual field is observed. Kerkhoff et al.[13] obtained this effect in 54% of patients, who were subjected to exercises in use of saccadic eye movements during 25 half-hour therapeutic sessions. In the majority of cases, the change did not exceed 8 degrees; however, there were also patients with 11-, 17- and even 24-degree visual field broadening.

Restoration of the visual field

In contrast to the above-described methods improving oculomotor compensation, the first-line goal of other training techniques in hemianopia is to broaden the area of perception of visual stimuli. In this approach, existence of the so-called residual area or residual vision is taken advantage of. This residual vision involves fragments of the dysfunctional visual field yet with partially preserved function[26]. This constitutes the basis of a phenomenon known as blindsight, „a vision despite blindness" that depends on partially preserved groups of relatively normally functioning cells located within the damaged visual cerebral cortex[24] or on alternative visual pathways originating in the retina and passing through the upper colliculi in the midbrain[27]. Ro and Rafal[28] add the third possibility to these mechanisms that assumes that visual impulses from the lateral geniculate bodies reach directly the secondary cerebral cortex without passing through the primary areas, which elicits visual sensations that are in some cases sufficient for differentiation of the stimuli. This refers to the particularly frequent patients' perception of sensation of movement and the ability to distinguish some colours. In case of colours, the hypothesis of the direct projection to the secondary visual cortex is more probable, as the cells of the upper colliculi are insensitive to the length of the light waves.

Patients are often unconscious as to the presence of the residual vision, so the typical method of uncovering the preserved abilities is the method of forced-choice. In an exercise using this forced-choice methodology, the patient is usually asked to react to a stimulus (e.g. by responding: „present" / „absent"), even if the patient is not sure of what actually appeared in the visual field. It becomes evident that patients react generally better than at a random level[29]. The fact of the existence of the sub-threshold, subconsciuos perception of visual stimuli from the area involved in the visual field defect is also confirmed by physiological reflexes, e.g. changes in skin resistance[30], pupillary responses[31] and orientation-related saccadic eye movements[27]. Patients are able to localise the stimuli in the field contralateral to the hemispheric damage (especially those that appear suddenly), to differentiate them with respect to their spatial orientation and – rarer – with respect to their colour, movement direction and shape[29]. The phenomenon of residual vision was also experimentally "simulated" in studies using transcranial magnetic stimulation. In healthy participants, this evoked artificial focal „damage" due to temporary inhibition of the primary visual cortex activity, which was leading to formation of partial visual field defects[32]. The participants reacted at a better than random level although they were theoretically unable to detect stimuli appearing in the blind parts of the visual field.

Broadening of visual field was the outcome of regular perimeter-assisted training, one of the first studies of that type, conducted by Zihl and von Cramon[22]. Broadening of visual field was observed in all 12 participants in this study. Size of the restored visual field was, however, diverse and ranged from 1 to 25 degrees. Similarly, there was a diversity in the observed number of one-hour sessions needed to broaden visual field by 1 degree (from 12 to 265). The authors note that even a small improvement of 2 degrees was associated with much better reading skills. Moreover, improvement in both the size of the visual field and visual acuity was found only during the time, when patients were subjected to exercises and no further changes were present following termination of the therapy.

Kasten and Sabel[23] created a computer software-assisted training mode that was conducted – for patients' convenience – at their homes. The training involved stimulation of the border region between the preserved and disturbed visual field, that is of the region of the likely residual vision. The exercises also comprised differentiation of visual stimuli (appearing in the field contralateral to the side of brain damage) with regard to shape and colour and detection of stimuli of minimal intensity. Besides, patients were exercised in maintaining stable eye fixation. Comparing the status before and after the therapy, a 42% broadening of the visual field was found in 9 of 11 exercising patients. Ability to differentiate simple shapes in the blind part of the field was improved by 37% on average and differentiation of colours – by 26%. The authors showed that the magnitude of improvement was linearly related to the number of hours of the therapy. Ro and Rafal[28] point the attention, however, to a possibility of an influence on the effects of this therapy of the patients' tendency to compensatory fixing of sight towards the region of anopia. Lack of control for the fixation factor is, therefore, a drawback of this method.

The same group of investigators[33] conducted an analysis of visual function in 22 patients to assess durability of the effects of previously conducted training. Patients with a lesion that occurred more than one year earlier were selected to minimise the effect of spontaneous healing. In the follow-up study, time since therapy termination ranged from 6 to 47 months. The effects of training proved to be stabile, although a slight (statistically insignificant) deterioration was observed as compared to the evaluation performed immediately after the therapy.

A group of researchers from Finland subjected two patients with hemianopia to a training in detection of simple visual stimuli flashing at various frequency and in recognition of flashing letters placed in the region of visual field defect[34]. Therapy duration was one year and patients exercised twice a week for 60-120 minutes during each session. Both patients equally easily detected stimuli in both halves of their visual fields up to 20 degrees from the central point and one of the patients reacted symmetrically to stimuli located up to 30 degrees from the central point. Patients also reported subjectively better vision in every-day life (orientation in the crowd, crossing the street etc.). Increased activity of the neural tissue during visual perception recorded using magnetoencephalography confirmed functional changes in the visual cortex associated with the observed improvement. Interestingly, in one patient, visual task-evoked cortical activity was observed only in the healthy hemisphere, which was also confirmed in a functional magnetic resonance study. The authors claim that both halves of the visual field were represented in the visual cortex of the undamaged hemisphere in this patient as a result of functional trans-mapping[35]. Fixation was controlled for in those case studies by the investigators during visual exercises and testing sessions, which constitutes a strong point of their methodology. Probability that the observed changes were associated with spontaneous improvement was low, as both patients started the therapy more than ten months after disease onset.

Apart from the above-presented therapeutic approaches, alternative therapies aiming at improvement of visual perception in patients with hemianopia are undertaken that are, so far, experimental. It is, for example, postulated to use prism glasses that would shift the peripheral image towards the central part of the retina. This is supposed to enlarge functional visual field[36]. The method, however, requires further evaluation.

Role of attention processes

In restoration of the disturbed visual function, the role of attention is specially emphasised. As it was stated by Williams and Gassel[26], visual field examined in a traditional way refers not only to the ability to passively register the stimuli, picture of which appears on the retina, but also reflects the activity of attention processes. Association between improvement in visual function and attention indicates, according to Zihl and von Cramon[22], that the level of functional activity of the visual cortex does not only depend on specific visual activity of neurones forming this cortex. Studies show that modulation of the visual signal by attention (involving increase in amplitude of cortical responses) induces an augmentation of capability to process information located in the field that attention is focused on[37-39]. Another fact becomes also evident that attention driven by spatial cues facilitates detection and differentiation of stimuli in the visual field with anopia[29,40,41].

CORTICAL BLINDNESS

Therapeutic approaches have also been undertaken in patients with the so-called cortical blindness, where anopia comprises both halves of the visual field. This type of disturbances, resulting from bilateral damage to the primary visual cortices, are relatively rare[42]. Bilateral hemispheric ischemia due to stroke within the territory supplied by the posterior cerebral artery is the most frequent cause; however, this dysfunction can also result from traumatic brain injury, carbon monoxide intoxication, intra-cerebral haemorrhage or sudden cardiac arrest[14]. Chronic blindness persists in approximately 25% of patients[42]; in the remaining patients, various degree of improvement was observed[43,44]. Dynamics of the process of healing from cortical blindness is greatest between the 8th and 12th week following onset of symptoms[45].

Number of studies using specific rehabilitation methods with confirmed efficacy in relatively low in this group of patients. Yet, it was demonstrated that systematic (even passive) visual training may lead to an improvement in detection and differentiation of visual stimuli in children with severe visual disturbances due to peri-natal brain damage[46] and in adults, several years after stroke or acute ischaemia[47]. Improvement in visual function – in the group undergoing therapy – was accompanied by an increase (in comparison to the pre-training period of time) in cerebral tissue activity around the foci of lesions in the occipital and parietal cortex, which was documented in functional neuro-imaging studies. Preserved, even at a minimal level, activity of neurones in the damaged areas of the primary and secondary visual cortex proved to be essential for the process of restoration of vision.

Cortical blindness is sometimes accompanied by visual hallucinations and unawareness of the loss of vision or a limited insight into the existing deficit. Such configuration of symptoms is referred to as the Anton syndrome[48]. In spite of the evident disability, patients ignore symptoms of the disease subjectively perceiving complex visual sensations that he interprets as seeing real images and events. If asked, such patients deny visual perception deficits, they claim that they can see normally while describing the „visually perceived" environment completely inadequately to the real situation. Confabulations of this type likely result from visual hallucinations that – with concomitant anosognosia, i.e. unawareness of the disease-associated deficit – provide patients with an illusion of preserved vision by replacing real perception. Anton's syndrome is one of the most cognitively spectacular and intriguing example of impaired insight into patients' self deficits and limitations associated with a disease. The syndrome is likely to result from a dysfunction in the system monitoring the flow of visual information in the brain[49]. It is suspected that in patients with this syndrome, in the preserved parts of the cortex, visual representations formed before the lesion are activated, which causes patients to experience images that the monitoring system considers as normal and real perception. In such cases, a help in making patients aware of the nature of their untypical disturbances is an important part of therapy, which, however, is not easy, as patients subjectively do „perceive" the non-existing reality.

CONCLUSIONS

To summarise, results of the existing studies clearly indicate that therapeutic interventions that would help in the process of healing and rehabilitation in patients suffering from post-stroke visual disturbances are possible. Detailed analyses indicate that the improvement is possible both in a mechanism of spontaneous process of restoration of the neural visual system (especially during the first moths following disease onset) and as a result of functional reorganisation induced by training. The healing process is usually supported by several factors. Apart from restoring the visual field, oculomotor compensation is involved, as well as an ability of fast scanning of the visual perception field and compensatory use of attention processes. It should, however, be noted that there are studies that do not confirm the satisfactory effectiveness of the described forms of therapy[50] and the inconsistencies may result e.g. from the type of applied methods or the training duration or intensity. Kasten and Sabel[23] demonstrated that the first positive result of therapy is seen after 30 hours of exercises on average and marked improvement – as late as after 100 hours of specific training. Such variables as patients' age and size of the visual field defect can affect training results (patients with smaller defects – according to many authors – have a higher chance of improvement[23]). Nevertheless, Kerkhoff et al.[13] found no associations between the degree of improvement and age, gender, side of the lesion or time from symptoms onset.

The described problem is an open topic in neuro-rehabilitation and the yearly growing number of publications pertaining to this issue proves that there is high interest in the problem of restoration of visual perception following brain damage.

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