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CASE REPORT

Rehabilitation of hemianopia and visuospatial hemineglect with a mixed intervention including adapted boxing therapy: An exploratory case study

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ABSTRACT

Visual field loss and visuospatial neglect are frequent consequences of cerebral stroke. They often have a strong impact on independence in many daily activities. Rehabilitation aiming to decrease these disabilities is therefore important, and several techniques have been proposed to foster awareness, compensation, or restitution of the impaired visual field. We here describe a rehabilitation intervention using adapted boxing therapy that was part of a pluridisciplinary intervention tailored for a particular case. A 58-year-old man with left homonymous hemianopia (HH) and mild visuospatial hemineglect participated in 36 sessions of boxing therapy six months after a right temporo-occipital stroke. Repeated stimulation of his blind and neglected hemifield, and training to compensate for his deficits through improved use of his healthy hemifield were performed through boxing exercises. The patient showed a stable HH before the beginning of the training. After six months of boxing therapy, he reported improved awareness of his visual environment. Critically, his HH had evolved to a left superior quadrantanopia and spatial attention for left-sided stimuli had improved. Several cognitive functions and his mood also showed improvement. We conclude that boxing therapy has the potential to improve the compensation of visuospatial impairments in individual patients with visual field loss.

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Introduction

Visual field loss and neglect are distinct, yet often concomitant sequelae of unilateral brain damage. The former is considered a perceptual defect of the visual

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field and is caused by damage to the visual cortex or pathways (Zihl, 1995). Homonymous hemianopia (HH) is the contralesional loss of one-half of the visual field in both eyes. It is the most common visual disorder after stroke, with a prevalence of 20–57% (Rowe et al., 2009). Visuospatial neglect is the contralesional reduction of awareness for the spatial side opposite to the lesioned area. The prevalence is on average 30% after unilateral lesion in stroke patients (Esposito et al., 2021).

The consequences of HH and visuospatial neglect on patients' autonomy in daily activities, such as reading, cooking, driving, spatial navigation, or simply moving within their homes, are often substantial. Because of these handicaps, the quality of life is obviously reduced, and patients present subjective complaints even years after injury (Papageorgiou et al., 2007). Only 10% of patients with HH fully recover within the first two weeks (Gray et al., 1989). Visual recovery is partial in the subacute phase and becomes negligible after 10–12 weeks (Gray et al., 1989; Tiel & Kolmel, 1991; Zhang et al., 2006). Spontaneous recovery of visuospatial hemineglect occurs within the first six months and is still present at three months in 17% of patients with right brain lesions (Ringman et al., 2004).

With time, some patients with remaining visual field difficulties spontaneously use strategies to compensate for their blind and/or neglected hemifield (Fellrath & Ptak, 2015; Zihl, 1995). However, some compensation strategies are not functional, and many patients continue to show impairment in everyday life. Rehabilitation of both HH and visuospatial hemineglect is therefore highly recommended and should start early for a positive prognosis. Some interventions for these disorders are similar and often involve visual field training (e.g., Kerkhoff et al., 2021; Leitner & Hawelka, 2021). There are four different forms of intervention (Schofield & Leff, 2009), which are sometimes combined (Bowen et al., 2013).

1. Substitutive compensation with external aids to help the patient interact with his visual environment. The best known is the prism goggle, an optical device that induces a deviation of the blind/neglected field towards the healthy side of the visual field. Optical aids may be efficient though not when patients present visual attentional symptoms (Ptak, 2017), but are unfortunately prone to cause diplopia and visuospatial confusion in certain patients (Trauzettel-Klosinski, 2010).
2. Behavioural compensation is the training to use the normal hemifield for contralesional visual perception and attentional focus instead of the blind and neglected hemifield respectively. Head and eye movements towards the blind/neglected hemifield are trained in order to create an automatic behaviour (Hill et al., 2015; Pambakian et al., 2004; Zihl, 1995).
3. Restoration and increased awareness of the problematic hemifield via passive repeated sensory stimulation. This approach is based on the idea

that recurrent administration of visual stimuli in the blind and/or neglected hemifield of patients promotes neural plasticity. However, this approach is highly controversial (see Das & Huxlin, 2010; Huxlin et al., 2009; Kasten et al., 1998; Melnick et al., 2016; against: Schreiber et al., 2006).

4. Multisensory stimulation: combining visual and auditory stimulation in order to activate multisensory integration for visual restoration and improved awareness of the visual field (Bolognini et al., 2005; Rowland et al., 2023; Zigiotto et al., 2021).

We here report the outcome of an interdisciplinary and complex intervention including physical, occupational, and neuropsychological therapies in a 58-year-old man six months after a posterior ischaemic stroke. The neuropsychological programme aimed to train visual attention, compensate for the blind hemifield and improve visual function in the blind hemifield by repeated stimulation. To this aim we applied adapted boxing therapy (ABT), which was previously used to improve mobility, balance, and quality of life in patients with Parkinson's disease (Combs et al., 2011; Morris et al., 2019). Boxing training has also been applied to improve balance, motor ability, and cognitive functions in stroke patients (Ersoy & Iyigun, 2021; Park et al., 2017). Park et al. (2017) found that boxing therapy even enhanced quality of life to a greater extent than physical therapy alone.

To our knowledge, this is the first case report of boxing therapy in the rehabilitation of visual field loss and impaired visuospatial attention. Boxing movements require motor activation and advanced coordination of the upper body, as well as visuomotor coordination when patients are instructed to hit visual targets. If the targets are moving from one hemifield to another, it also trains the detection of and reaction to stimuli in the blind or neglected hemifield. Stimulation is not only visual, but also auditory and tactile (when the glove hits the target), and requires high degrees of balance and postural control. Because of the multisensory nature of ABT, we hypothesized that this method may improve the active compensation of visual field defects and visuospatial neglect.

Methods

Case report

The patient was a right-handed, previously healthy, 58-year-old man. He owned a car garage and was particularly under pressure due to a high bankruptcy risk when suffering a stroke. He was immediately admitted to the hospital, where neurovascular and brain imaging showed an acute, right temporo-occipital lesion (see Figure 1), probably caused by an embolic stroke. An initial neuropsychological assessment indicated moderate to severe apraxia, executive,

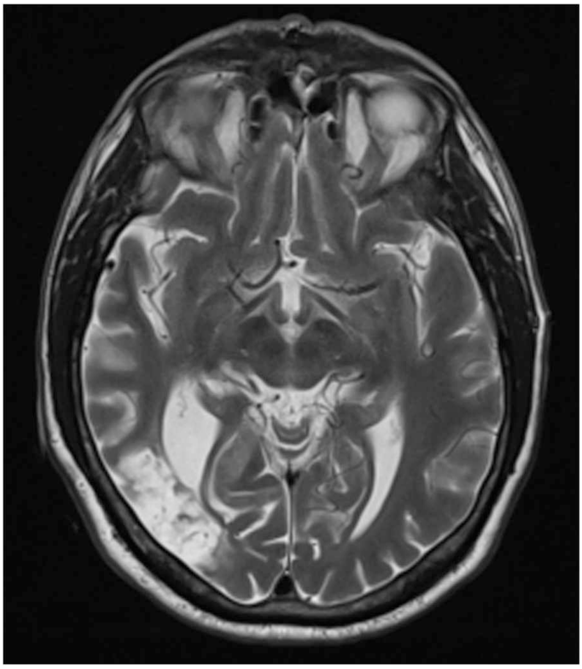

Figure 1. Brain MRI of the patient performed at two weeks. Axial view fluid-attenuated inversion recovery T2-weighted MR image shows hyperintense lesions in the right temporo-occipital area.

attentional, and verbal memory impairments, associated with severe underuse of his left arm and a complete left HH. Even though relatives described his personality as exuberant, the patient was more impulsive and disinhibited than usual and was easily angered when exposed to the slightest frustration.

In spite of these results and contrary to medical advice, the patient refused to be transferred to the neurorehabilitation unit and returned home to take up work in his garage. However, because of his cognitive deficits, his employment and financial situation worsened. Five months after his first hospitalization, he asked to enter an inpatient rehabilitation facility, as he saw no other option.

Pre-intervention emotional and cognitive evaluation

The Hospital Anxiety and Depression Scale (HADS) showed highly significant scores (see Table 1). As previously mentioned, the patient showed strong signs of anger when he was upset. An emotion regulation questionnaire (ERQ; Gross & John, 2003) indicated that the patient was much more likely to use an inhibition strategy than a reappraisal strategy when experiencing negative emotions (see Table 1).

On his first day upon admission, he appeared depressed yet motivated to undergo a novel evaluation of his cognitive functioning. He repeated many times: "I would like to know who I am now because I do not recognize

Table 1. Results of the cognitive and emotional assessment before and after the intervention.

Domain	Pre-treatment		Post-treatment	
Test	Score	Percentile	Score	Percentile
Memory				
Digit span, WAIS IV	3	Pc 1	6	Pc 9
Score forward order				
Score backward order	5	Pc 9	5	Pc 9
Pre-treatment: *12 words, WMS III*	24/48	Pc 16	45/75	Pc 16–25
Post-treatment: *RAVLT*				
Total learning score				
Delayed recall retention score	37.5%	PC 5	80%	Pc 69
Executive functions				
TAP Go/No-Go	437 ms	Pc 38	447 ms	Pc 58
Median time reaction				
Standard deviation	150 ms	Pc 3	151 ms	Pc 3
Errors	5	Pc 7	3	Pc 18
Semantic verbal fluency	17	Pc 2–5	22	Pc 10–25
Luria's graphical alternating series, number of correct sequences	> 5	Pc 1	0	Norms
Attention				
TAP Alert	242 ms	Pc 34	264 ms	Pc 31
Mean time reaction (tonic condition)				
Standard deviation (tonic condition)	20 ms	Pc 92	50 ms	Pc 30
Mean time reaction (phasic condition)	310 ms	Pc 7	240 ms	Pc 25
Standard deviation (phasic condition)	49 ms	Pc 31	33 ms	Pc 42
TAP Divided attention	518 ms	Pc 90	940 ms	Pc 1
Mean time reaction (visual condition)				
Standard deviation (visual condition)	147 ms	Pc 1	98 ms	Pc 27
Mean time reaction (auditory condition)	644 ms	Pc 50	650 ms	Pc 50
Standard deviation (auditory condition)	286 ms	Pc 2	150 ms	Pc 34
Errors	14	Pc 4	10	Pc 6
(both conditions)				
Lateralized attention				
Bell Test	190 sec.	Impaired	310 sec.	Impaired
Time	5	Impaired	2	Normal
Left columns omissions	2		0	
Central omissions	4		2	
Right columns omissions	12		4	
Total omissions				
Visuoconstructive ability				
Cerad score	8	impaired	11	normal
EMOTION				
HADS	19	Cut-off 11	9	Cut-off 11
Anxiety	16	Cut-off 11	8	Cut-off 11
Depression				
ERQ, strategies	21 / 28	–	21 / 28	–
Inhibition	26 / 42		40 / 42	
Reappraisal				

Note: CERAD: Consortium to Establish a Registry for Alzheimer's Disease; ERQ: Emotional Regulation Questionnaire; HADS: Hospital Anxiety and Depression Scale; RAVLT: Rey Auditory Verbal Learning Test; TAP: Test of Attentional Performance; WAIS: Wechsler Adult Intelligence Scale; WMS: Wechsler Memory Scale.

myself." He was collaborative, fully oriented in time and space, and alert during testing. Verbal expression was fluent except for slight word-finding difficulties. He was aware of his cognitive and motor impairments and their consequences in daily life. He was anxious about his performance when faced with failure during the exam.

During anamnesis and tests, the examiner regularly had to recall the purpose of the exam because the patient was voluble and digressive. In addition, he made numerous comments during the tests and repeatedly exhibited impulsive and inappropriate behaviours (e.g., he pulled out a yellow card to let the examiner know he was not happy, spoke rudely, and became easily angry). Impulsiveness when starting tasks and a slight psychomotor slowing were noted. When moving in the corridors, he often seemed to be off balance (he staggered) and regularly needed to be warned to avoid bumping into obstacles on his left.

Table 1 summarizes the results of formal cognitive tests. Before the training, the patient exhibited a mild left egocentric visuospatial neglect that was clinically manifest in reading (he frequently missed the first word of each line in text) and writing or drawing (there was a mild right deviation of the margin towards the right side of the page). There was however only one more omission on the left side compared to the right side in a cancellation task (Bell Test). Time to perform the task was abnormally slow as he had no systematic visual search strategy. The patient correctly placed eight cities on a blank map of Switzerland. In addition, he had moderate anterograde memory and executive deficits, as well as impaired divided attention, alertness, and visual-constructive function. Visual identification appeared to be slightly impaired, which could be explained by poor adaptation to the visual field impairment. Orientation, language skills, reasoning, and working memory performance were within norms.

Pre-intervention visual field assessment

A computer-assisted binocular perimetry test (TAP, Visual Field CIT) indicated left hemifield impairment with eight omissions in the left visual field (LVF), including seven in the lower quadrant. Median reaction time was significantly slower in the LVF (774 ms, Pc 8) than in the right visual field (RFV; 518 ms, Pc 27). Statistical analyses performed on the reaction times confirmed the difference (Mann–Whitney *U* test, $p < .01$). This test did not control for head movements.

Visual fields were evaluated for each eye separately with static stimuli using the Octopus device (Octopus 900) – which monitors but does not assess the frequency of fixation losses – at one and at five months post-stroke. Both evaluations showed complete impairment of the left inferior quadrant, and a patchy visual field impairment of the left upper quadrant (see Figure 3A,B). The average diffuse loss ("Diffuse defect, dB" or deviation from normal) compared to an age-appropriate population was significant for the left hemifield of both eyes (1 month: dB, left eye: 12.4; right eye: 11.3; 5 months: dB, left eye: 11.9; and right eye: 13.6, Figure 3D). A binocular visual field test indicated a depleted horizontal visual field of 130° (see Figure 3E).

The impact of visual impairment on daily life (Self-Report Questionnaire for Visual Impairment in Daily Life, Kerkhoff et al., 1994) was high with a score of 24 out of 48. The patient particularly emphasized the items "seeing obstacles in my path," "bumping into objects when I move," "finding objects on a table," "finding objects in a room," and "reading" as very frequent problems.

The following intervention was conducted after the patient had given written informed consent to participate in clinical studies at the University Hospitals of Geneva. This implies that all anamnestic, clinical (including neuropsychological test results) and diagnostic information of the patient could be used for research and publication purposes. The procedure was approved by the Ethics Committee of the University of Geneva.

Procedure

The multidisciplinary intervention included three specific programmes on an outpatient basis which approximately began at the same time: physical, occupational, and neuropsychological (ABT) therapies. During the first three months, the patient received physical therapy (once a week for 30 minutes) to work on balance and posture, and occupational therapy (once a week for 30–45 minutes) to train executive skills in the activity of cooking, as well as spatial attention in moving around the street and in a supermarket. A compensatory approach to the visual impairments was used: the patient was regularly instructed to monitor the left side of his environment while doing activities and moving. ABT was carried out with two weekly sessions of approximately 55 minutes each over a six-month period.

The ABT equipment consisted of a pair of boxing gloves for the patient and a pair of black "bear paws" for the therapist (see Figure 1). Table 2 shows the details of the session schedule. Two different formats were used. A standard format (programme 1) to train spatial attention and an alternative format (programme 2) focusing on emotional expression and/or relational and emotional problem-solving. The alternative format was proposed occasionally when the patient was preoccupied with personal problems. During these alternative sessions, family problems, his frustration related to disabilities (especially driving) and anger over perceived past injustices (dismissal) were addressed.

In order to prevent injury, each session began with a body warm-up. The patient was then invited to freely express his or her emotional state and the events experienced since the last training. The objective was to provide psychological support with active listening and advice on problem-solving and emotional management. Along with the discussion, the patient hit a target (a raised bear paw) at his or her own pace with a break every two minutes. This part of the session also worked on the ability to perform dual tasks (speaking and hitting the target simultaneously).

Table 2. Sequence of the two programmes 1 and 2 used for the rehabilitation sessions.

Activities	Programme 1 (31 sessions) Time (minutes)	Programme 2 (5 sessions) Time (minutes)
Warm-up	5	5
Emotional expression	15	30–35
Spatial attention and visual stimulation training	35	15–20

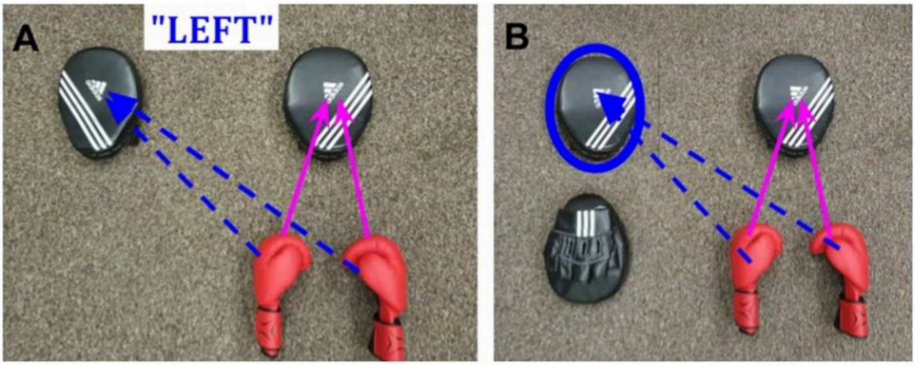

Figure 2. The two variants A and B used for boxing revalidation of hemianopia.

As shown in Figure 2, two variants were used for visual attention and visual stimulation training, each at approximately 50% for both programmes 1 and 2.

In variant A the patient always started by striking the target in his right visual field with both hands in alternation. At this stage, both targets were raised permanently. At irregular intervals, the therapist gave a verbal cue by saying "left," requiring the patient to hit the left target as quickly as possible and several times with both hands (between two and six strokes depending on whether the therapist held or lowered the bear paw) and then return to the right. Then the cycle started again. In variant B, the patient also started by striking the target located in his right visual field (this time the left target was lowered). Occasionally the therapist raised the left target (visual signal), requiring him to strike as fast as possible to the left several times, then come back to the right spontaneously or on the therapist's verbal incitement ("right"). Then, the cycle would start again.

Results of the pre-intervention and post-intervention evaluations were compared using descriptive statistics. Inferential statistics (non-parametric Mann–Whitney *U* test) were used for the visual field task which contained multiple data (Test of Attentional Performance, TAP, Visual Field).

Results

Post-intervention cognitive and emotional evaluation

The patient was very committed and motivated to follow the programme during the six months. He did not miss a single session. The two weeks without training were due to the therapist's absences (vacation). The total number of sessions was 36.

Mood was reported as generally stable and relatively good (he was still annoyed that he could not drive), in contrast to before the intervention. This was also supported by the HADS scores with a decrease in anxiety and depression scores from severe to mild symptomatology (see Table 1). ERQ scores indicated that while the patient still used an inhibition strategy to the same extent, he now also used a reappraisal strategy for negative emotions to a much greater extent (see Table 1).

Compared to the pre-intervention examination 6 months earlier, Table 1 shows that the cognitive picture had slightly improved, except for attentional capacities (non-lateralized), which remained globally stable. The performance was now within the norms for verbal episodic memory. The visuo-constructive deficit seemed to be less pronounced, and the executive capacities went from moderate-to-mild impairment. Crucially, signs of visuospatial neglect were virtually absent; there were almost no omissions in reading and less deviation of the margins in writing or drawing. Moreover, the patient made the same number of omissions (2) between the left and the right side in a cancellation task, though his response time remained slow due to the absence of a visual search strategy.

Post-intervention visual field assessment

Only one omission was noted in the lower left quadrant on the computer-assisted visual field examination (TAP, Visual Field). Median reaction times (RTs) were within norms for both hemifields (left: 696 ms, Pc 21; right: 576 ms; Pc 31). There was a significant trend towards slower mean RTs in the left compared to the right visual field (Mann–Whitney U test, $p = .056$). Independently of the quadrant, no significant differences were found between the pre- and the post-intervention RTs (Mann–Whitney U tests, all $p > .3$).

Octopus perimetry revealed a significant mean diffuse loss ("Diffuse defect, dB" or deviation from normal) in the left and right eye compared to an age-appropriate population, but less than before the intervention (dB, left eye: 9.8; right eye: 8.7; see Figure 3B–D). Compared to the pre-test, the horizontal visual field was improved by nearly 25% (24.4%) in the left superior quadrant in the binocular visual field test (Figure 3E).

The impact of visual impairment in daily life (Visual Impairment in Daily Life Questionnaire, Kerkhoff et al., 1994) decreased by 14 points six months after the start of the intervention (score: 10/48). The patient now rated reading as a moderate problem, and "seeing obstacles in one's path," "bumping into obstacles," and "finding objects" as minor (infrequent) problems; "travelling on public transportation" and "finding one's way" were no longer considered problems.

Discussion

This exploratory case report describes a comprehensive, interdisciplinary intervention for visual field loss and neglect, including adapted boxing therapy (ABT). The patient, a 58-year-old man who had suffered from an embolic stroke, initially refused to accept the proposed in-patient treatment, including conventional neuropsychological therapy. Hence, a more suitable multimodal

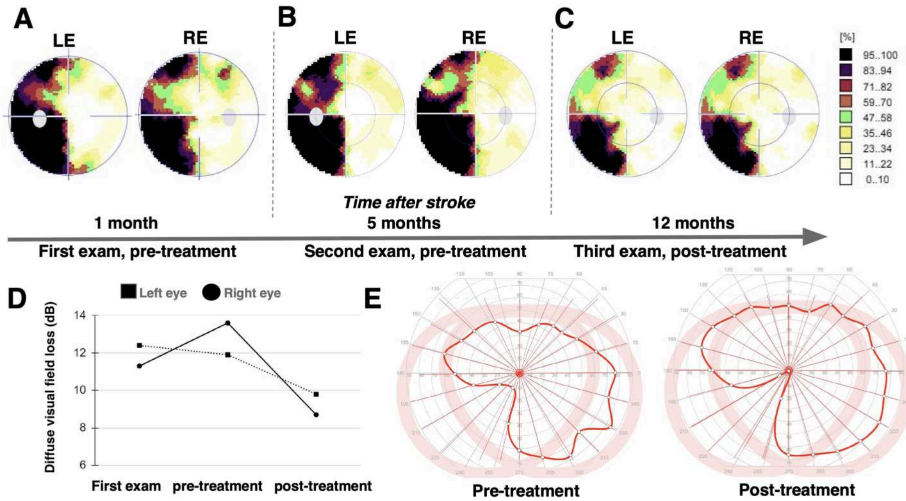

Figure 3. (A) Visual field integrity for each eye one month, (B) five months (pre-treatment), and (C) 12 months (post-treatment) after stroke. The colour scale indicates the proportion of missed targets at each position of the visual field. (D) Mean diffused visual field loss for the left and the right eye during the initial exam (one month after stroke), during the second pre-treatment exam, and during the post-treatment exam. (E) Binocular visual field pre-treatment and post-treatment. LE: left eye; RE: right eye.

intervention was specifically designed for him. The advantage of ABT, with regard to this particular patient, is that it allows treating visual field impairments and emotional distress in the same sessions. Boxing exercises aimed at training the patient to compensate for his HH and improving vision in his blind and slightly neglected left hemifield.

Six months after the beginning of the multidisciplinary intervention, the patient subjectively observed considerable progress in coping with his visual environment. Descriptive statistics showed that the left superior field, which was less impaired than the left inferior field before the treatment, had completely recovered; his HH had evolved to a quadrantanopia. Furthermore, neglect of the left hemifield also appeared to regress during the treatment. These changes allowed the patient to take up driving, which was very important to him, as he was living far from town and working as a garage owner. Since ABT was part of a multidisciplinary treatment programme, we cannot conclude that it was responsible for all positive effects of the intervention. Furthermore, insufficient experimental control for potential confounds precludes strong conclusions regarding possible causal explanations of our findings.

At first glance, it could be argued that natural and spontaneous recovery was fully responsible for these positive results. The fact that the patient also improved in some cognitive domains (mainly memory and executive functions) speaks in that favour. However, there was no evolution during the first 5 months following stroke and before the multidisciplinary intervention started, and spontaneous recovery of HH after six months is considered unlikely (Zhang et al., 2006). Our data also argue against a general time-related improvement of non-lateralized visual attention, as the patient solely performed better in visual attentional tasks after introducing the therapy for stimuli appearing in the left visual field.

Whether the visual field may be improved with specific restoration therapy is a matter of controversy. Visual restoration training typically involves visual stimuli presented in the blind hemifield or at the border of a visual field defect. Some studies reported a decrease in impairment, while other studies observed no change after numerous repeated stimulations of the same visual area (Balliet et al., 1985; Kasten et al., 1998; Matteo et al., 2016; Trauzettel-Klosinski, 2010; Zihl & Von Cramon, 1979). An alternative to restoration training is compensation training. This technique aims at establishing automatic visual attention and eye movements towards the blind and/or neglected side. Rehabilitation studies showed that such training enhances independence (Kerkhoff et al., 2021; Nelles et al., 2001), and quality of life (Roth et al., 2009), but does not restore visual capacities in the blind field (Nelles et al., 2001). However, the visual field improvement might not reflect behavioural compensation alone (e.g., systematically directing gaze towards the impaired hemifield), as the perimetry test detects compensatory eye movements and thus prevents compensation. Furthermore, the patient was more accurate at target detection in his left superior visual hemifield after the intervention, but not faster in a computerized task allowing head movements. This finding argues against behavioural compensation, which would become evident in the latter task.

The observed improvements in visual impairment and neglect signs might be related to the multisensory nature of ABT. Using simultaneous auditory and visual stimulations in the blind hemifield, previous studies found that visual detection progressively increased with intensive training (Bolognini et al., 2005; Rowland et al., 2023). Multisensory stimulation has also shown promising results in visuospatial neglect patients (Heyse et al., 2022; Zigiotto et al., 2021). For example, Heyse et al. (2022) conducted a successful music therapy intervention in four neglected patients using virtual reality to train simultaneously multiple sensory modalities: hearing, vision, touch and self-motion.

The neurobiological mechanisms underlying the recovery of the visual field with rehabilitation have not been fully understood yet. The most common hypothesis is that repetitive training would reactivate healthy neurons in the border region of the lesion site by strengthening synaptic connections (Sabel et al., 2011). Another explanation, complementary to the previous one, is based on "blindsight." Despite large lesions to the occipital lobe, including the striate cortex, some patients retain the ability to make reasonably accurate saccades to visual targets presented in their blind hemifield (Benevento & Yoshida, 1981; Weiskrantz et al., 1974). This phenomenon depends on unconscious processes, probably mediated via subcortical structures. It is believed that by recurrent stimulations of the residual unconscious visual capacities, dynamic plasticity would be triggered and impaired conscious vision could be restored. However, there is no direct evidence for either hypothesis. Several functional neuroimaging studies conducted with hemianopic patients rather suggest a reorganization of the brain after interventions aiming to restore the blind visual field. For example, Marshall et al. (2008) found that after one month of repetitive stimulations of the border zone adjacent to the blind hemifield, activation of the attentional network and of higher-order visual areas during border zone detection was significantly enhanced compared to seeing zone detection. In a single case study of a patient with HH (Henriksson et al., 2007), intensive training with a flickering stimulation task also induced a shift of brain response during the task towards several contralesional visual areas. Similarly, saccadic training with a behavioural compensation programme induced novel activations of the contralesional extrastriate cortex compared to baseline (Nelles et al., 2010). Another study suggested that functional connectivity between the precuneus and the occipital lobe predicts the outcome of behavioural compensation training in hemianopic patients (Halbertsma et al., 2020). Using a passive paradigm in animals relying exclusively on the inherent capacities of the brain for multisensory integration, Jiang et al. (2015) demonstrated neural reorganization after training. The paradigm involved presenting spatiotemporally aligned visual and auditory stimuli pairs within the blind hemifield of cats rendered hemianopic by unilateral lesions of the visual cortex. After one month of training, the multisensory output layers of the ipsilesional superior colliculus regained visual responsiveness. Together, current research suggests that recovery of visual field impairment is accompanied by increased involvement of healthy brain circuits rather than reactivation of the lesioned area.

Considering these points, the present ABT paradigm appears to involve a mix of two rehabilitation strategies: multisensory stimulation and the occupational therapy, and compensation training. The patient was trained to use his healthy right visual field to localize the visual targets located in his left visual field. Furthermore, wearing the gloves and hitting targets with them provoked both tactile and auditory stimulation, which in turn activated multisensory integration in the brain. The combination of tactile and auditory stimulation with visual input during training may have involved brain regions known to integrate sensory information from different modalities, such as the superior parietal cortex or the superior colliculus (Benavidez et al., 2021). In addition, the vestibular system was highly mobilized during the training, as visuomotor coordination, balance, and postural control were required. This may have enriched the interaction of visual and other types of sensory information from the body and the effectiveness of multisensory integration.

ABT differs from more traditional rehabilitation of visual field problems, as it involves motor activity of both arms. There are several published clinical reports hinting that active limb movements reduce visuospatial hemineglect (e.g., Halligan & Marshall, 1989; Robertson & North, 1993). Moreover, combining motor electrical stimulation of the left hand with visual scanning training seems to improve long-term visuospatial attention compared with visual scanning training alone (Polanowska et al., 2009). Via connectivity between motor and attention networks, active movements are thought to enhance activation of the ipsilateral hemisphere attention system and to improve visual exploration of extrapersonal space.

Physical activity per se could be another potential factor explaining the success of this interdisciplinary intervention in the present case. It is well-established that physical activity benefits stroke patients during rehabilitation (Han et al., 2017). Accumulating evidence in human and animal studies indicates that physical exercises support neuroplasticity by inducing changes at the cellular level (Pin-Barre & Laurin, 2015; Xing & Bai, 2020). Therefore, physical activity not only helps patients recover motor and sensory functions, but also cognitive functions (Hamilton & Rhodes, 2015). In addition to the effects of physical activity, the boxing exercises used here were explicitly designed to solicit working memory and several executive skills: mental flexibility, motor inhibition, and planning.

The rehabilitation training also improved the patient's emotional state, as he was unhappy with an initial proposition of traditional therapy for his HH, but was pleased when a new and original method was proposed. Furthermore, the patient was encouraged to express his anger and frustration through boxing, which certainly enhanced his mental well-being. Results also showed that he more often reappraised emotional events, which reduced its negative emotional impact (Gross & John, 2003). Physical activity in itself probably played a role in decreasing depressive symptoms too. This is in agreement with a meta-analysis of the literature by Eng and Reime (2014), who found that physical training in stroke patients, has a positive effect on depressive symptoms.

Limitations

The nature of the present research is exploratory and therefore has several limitations. Our study lacks additional measures over time (e.g., before, during, and after the intervention, or an additional late test to confirm that the progress is maintained over time), which are required for a single-case report. Perhaps most importantly, an experimental control condition, such as the comparison of ABT with a classical neuropsychological intervention, is lacking. Hence, we cannot draw causal conclusions from the results. The contribution of this paper is conceptual and sets up the basis to develop and evaluate similar complex interventions for stroke patients (see Skivington et al., 2021).

Conclusions

In sum, this single case report describes a tailored neuropsychological intervention made for a stroke patient within the context of a multidisciplinary intervention, and it indicates that ABT may be an interesting rehabilitation training alternative for visual field defects and visuospatial neglect. The advantages of ABT are multiple. It involves physical activity, allows the emotional expression of anger and frustration and mixes behavioural compensation with multisensory stimulation. However, boxing therapy cannot be recommended to everyone. Even if the physical intensity of the exercises can be adjusted to the patient's capacity, it requires a minimum level of cardiovascular endurance, visuomotor coordination, and upper limb motor functioning. Furthermore, boxing training should be appealing to the patient. Finally, it is important to point out that this case report represents only the first one published in the literature, and that more clinical studies including control conditions – unlike the present case – are needed before standardizing this method for the rehabilitation of hemifield problems.

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References

Balliet, R., Blood, K. M. T., & Bach-Y-Rita, P. (1985). Visual field rehabilitation in the cortically blind? *Journal of Neurology, Neurosurgery and Psychiatry*, *48*(11), 1113–1124. https://doi.org/10.1136/jnnp.48.11.1113

Benavidez, N. L., Bienkowski, M. S., Zhu, M., Garcia, L. H., Fayzullina, M., Gao, L., Bowman, I., Gou, L., Khanjani, N., Cotter, K. R., Korobkova, L., Becerra, M., Cao, C., Song, M. Y., Zhang, B., Yamashita, S., Tugangui, A. J., Zingg, B., Rose, K., … Dong, H. W. (2021). Organization of the inputs and outputs of the mouse superior colliculus. *Nature Communications*, *12*(1), 4004. https://doi.org/10.1038/s41467-021-24241-2

Benevento, L. A., & Yoshida, K. (1981). The afferent and efferent organization of the lateral geniculo-prestriate pathways in the macaque monkey. *Journal of Comparative Neurology*, *203*(3), 455–474. https://doi.org/https://doi.org/10.1002cne.902030309

Bolognini, N., Rasi, F., Coccia, M., & Làdavas, E. (2005). Visual search improvement in hemianopic patients after audio-visual stimulation. *Brain*, *128*(12), 2830–2842. https://doi.org/10.1093/brain/awh656

Bowen, A., Hazelton, C., Pollock, A., & Lincoln, N. B. (2013). Cognitive rehabilitation for spatial neglect following stroke. *The Cochrane Database of Systematic Reviews*, *7*.

Combs, S. A., Dyer Diehl, M., Staples, W. H., Conn, L., Davis, K., Lewis, N., & Schaneman, K. (2011). Boxing training for patients with Parkinson disease: case series. *Physical therapy*, *91*(1), 132–142. https://academic.oup.com/ptj/article/91/1/132/2735142.

Das, A., & Huxlin, K. R. (2010). New approaches to visual rehabilitation for cortical blindness: Outcomes and putative mechanisms. *The Neuroscientist*, *16*(4), 374–387. https://doi.org/10.1177/1073858409356112

Eng, J. J., & Reime, B. (2014). Exercise for depressive symptoms in stroke patients: A systematic review and meta-analysis. *Clinical Rehabilitation*, *28*(8), 731–739. https://doi.org/10.1177/0269215514523631

Ersoy, C., & Iyigun, G. (2021). Boxing training in patients with stroke causes improvement of upper extremity, balance, and cognitive functions but should it be applied as virtual or real? *Topics in Stroke Rehabilitation*, *28*(2), 112–126. https://doi.org/10.1080/10749357.2020.1783918

Esposito, E., Shekhtman, G., & Chen, P. (2021). Prevalence of spatial neglect post-stroke: A systematic review. *Annals of Physical and Rehabilitation Medicine*, *64*(5), 101459. https://doi.org/10.1016/j.rehab.2020.10.010

Fellrath, J., & Ptak, R. (2015). The role of visual saliency for the allocation of attention: Evidence from spatial neglect and hemianopia. *Neuropsychologia*, *73*, 70–81. https://doi.org/https://doi.org/10.1016j.neuropsychologia.2015.05.003

Gray, C. S., French, J. M., Bates, D., Cartlidge, N. E. F., Venables, G. S., & James, O. F. W. (1989). Recovery of visual fields in acute stroke: Homonymous hemianopia associated with adverse prognosis. *Age and Ageing*, *18*(6), 419–421. https://doi.org/10.1093/ageing/18.6.419

Gross, J. J., & John, O. P. (2003). Individual differences in Two emotion regulation processes: Implications for affect, relationships, and well-being. *Journal of Personality and Social Psychology*, *85*(2), 348–362. https://doi.org/10.1037/0022-3514.85.2.348

Halbertsma, H. N., Elshout, J. A., Bergsma, D. P., Norris, D. G., Cornelissen, F. W., van den Berg, A. V., & Haak, K. V. (2020). Functional connectivity of the precuneus reflects effectiveness of visual restitution training in chronic hemianopia. *NeuroImage: Clinical*, *27*, 102292. https://doi.org/https://doi.org/10.1016j.nicl.2020.102292

Halligan, P. W., & Marshall, J. C. (1989). Laterality of motor response in visuo-spatial neglect: A case study. *Neuropsychologia*, *27*(10), 1301–1307. https://doi.org/https://doi.org/10.10160028-3932(89)90042-0

Hamilton, G. F., & Rhodes, J. S. (2015). Chapter sixteen - exercise regulation of cognitive function and neuroplasticity in the healthy and diseased brain. In C. B. T.-P. in M, B. and T, & S. Bouchard (Eds.), *Molecular and cellular regulation of adaptation to exercise* (Vol. 135, pp. 381–406).Academic Press. https://doi.org/https://doi.org/10.1016bs.pmbts.2015.07.004

Han, P., Zhang, W., Kang, L., Ma, Y., Fu, L., Jia, L., Yu, H., Chen, X., Hou, L., Wang, L., Yu, X., Kohzuki, M., & Guo, Q. (2017). In J. Xiao (Ed.), *Clinical evidence of exercise benefits for stroke BT - exercise for cardiovascular disease prevention and treatment: From molecular to clinical, part 2* (pp. 131–151). Singapore: Springer. https://doi.org/10.1007/978-981-10-4304-8_9

Henriksson, L., Raninen, A., Näsänen, R., Hyvärinen, L., & Vanni, S. (2007). Training-induced cortical representation of a hemianopic hemifield. *Journal of Neurology, Neurosurgery and Psychiatry*, *78*(1), 74–81. https://doi.org/10.1136/jnnp.2006.099374

Heyse, J., Carlier, S., Verhelst, E., Vander Linden, C., De Backere, F., & De Turck, F. (2022). From patient to musician: A multi-sensory virtual reality rehabilitation tool for spatial neglect. *Applied Sciences (Switzerland)*, *12*(3), 1242. https://doi.org/10.3390/app12031242

Hill, D., Coats, R. O., Halstead, A., & Burke, M. R. (2015). A systematic research review assessing the effectiveness of pursuit interventions in spatial neglect following stroke. *Translational Stroke Research*, *6*(6), 410–420. https://doi.org/10.1007/s12975-015-0420-z

Huxlin, K. R., Martin, T., Kelly, K., Riley, M., Friedman, D. I., Burgin, W. S., & Hayhoe, M. (2009). Perceptual relearning of complex visual motion after V1 damage in humans. *Journal of Neuroscience*, *29*(13), 3981–3991. https://doi.org/10.1523/JNEUROSCI.4882-08.2009

Jiang, H., Stein, B. E., & Mchaffie, J. G. (2015). Multisensory training reverses midbrain lesion-induced changes and ameliorates haemianopia. *Nature communications*, *6*(1), 7263.

Kasten, E., Wüst, S., Behrens-Baumann, W., & Sabel, B. A. (1998). Computer-based training for the treatment of partial blindness. *Nature Medicine*, *4*(9), 1083–1087. https://doi.org/10.1038/2079

Kerkhoff, G., Münβinger, U., & Meier, E. K. (1994). Neurovisual rehabilitation in cerebral blindness. *Archives of Neurology*, *51*(5), 474–481. https://doi.org/10.1001/archneur.1994.00540170050016

Kerkhoff, G., Rode, G., & Clarke, S. (2021). Treating neurovisual deficits and spatial neglect. In T. Platz (Ed.), *Clinical pathways in stroke rehabilitation. Evidence-based clinical practice recommendations* (pp. 191–217). Springer.

Leitner, M. C., & Hawelka, S. (2021). Visual field improvement in neglect after virtual reality intervention: A single-case study. *Neurocase*, *27*(3), 308–318. https://doi.org/10.1080/13554794.2021.1951302

Marshall, R. S., Ferrera, J. J., Barnes, A., Zhang, X., O'Brien, K. A., Chmayssani, M., Hirsch, J., & Lazar, R. M. (2008). Brain activity associated with stimulation therapy of the visual borderzone in hemianopic stroke patients. *Neurorehabilitation and Neural Repair*, *22*(2), 136–144. https://doi.org/10.1177/1545968307305522

Matteo, B. M., Vigano, B., Cerri, C. G., & Perin, C. (2016). Visual field restorative rehabilitation after brain injury. *Journal of Vision*, *16*(9), 11–11. https://doi.org/10.1167/16.9.11

Melnick, M. D., Tadin, D., & Huxlin, K. R. (2016). Relearning to see in cortical blindness. *Neuroscientist*, *22*(2), 199–212. https://doi.org/10.1177/1073858415621035

Morris, M. E., Ellis, T. D., Jazayeri, D., Heng, H., Thomson, A., Balasundaram, A. P., & Slade, S. C. (2019). Boxing for Parkinson's disease: Has implementation accelerated beyond current evidence? *Frontiers in Neurology*, *10*, https://doi.org/10.3389/fneur.2019.01222

Nelles, G., Esser, J., Eckstein, A., Tiede, A., Gerhard, H., & Diener, H. C. (2001). Compensatory visual field training for patients with hemianopia after stroke. *Neuroscience Letters*, *306*, 189–192. www.elsevier.com/locate/neulet

Nelles, G., Pscherer, A., de Greiff, A., Gerhard, H., Forsting, M., Esser, J., & Diener, H. C. (2010). Eye-movement training-induced changes of visual field representation in patients with post-stroke hemianopia. *Journal of Neurology*, *257*(11), 1832–1840. https://doi.org/10.1007/s00415-010-5617-1

Pambakian, A. L. M., Mannan, S. K., Hodgson, T. L., & Kennard, C. (2004). Saccadic visual search training: A treatment for patients with homonymous hemianopia. *Journal of Neurology, Neurosurgery and Psychiatry*, *75*(10), 1443–1448. https://doi.org/10.1136/jnnp.2003.025957

Papageorgiou, E., Hardiess, G., Schaeffel, F., Wiethoelter, H., Karnath, H.-O., Mallot, H., Schoenfisch, B., & Schiefer, U. (2007). Assessment of vision-related quality of life in patients with homonymous visual field defects. *Graefe's Archive for Clinical and Experimental Ophthalmology*, *245*(12), 1749–1758. https://doi.org/10.1007/s00417-007-0644-z

Park, J., Gong, J., & Yim, J. (2017). Effects of a sitting boxing program on upper limb function, balance, gait, and quality of life in stroke patients. *NeuroRehabilitation*, *40*, 77–86. https://doi.org/10.3233/NRE-161392

Pin-Barre, C., & Laurin, J. (2015). Physical exercise as a diagnostic, rehabilitation, and preventive tool: Influence on neuroplasticity and motor recovery after stroke. *Neural Plasticity*, *2015*. https://doi.org/10.1155/2015/608581

Polanowska, K., Seniów, J., Paprot, E., Leśniak, M., & Członkowska, A. (2009). Left-hand somatosensory stimulation combined with visual scanning training in rehabilitation for post-stroke hemineglect: A randomised, double-blind study. *Neuropsychological Rehabilitation*, *19*(3), 364–382. https://doi.org/10.1080/09602010802268856

Ptak, R. (2017). What role for prism adaptation in the rehabilitation of pure neglect dyslexia? *Neurocase*, *23*(3–4), 193–200. https://doi.org/10.1080/13554794.2017.1361452

Ringman, J. M., Saver, J. L., Woolson, R. F., Clarke, W. R., & Adams, H. P. (2004). Frequency, risk factors, anatomy, and course of unilateral neglect in an acute stroke cohort. *Neurology*, *63*(3), 468–474. https://doi.org/10.1212/01.WNL.0000133011.10689.CE

Robertson, I. H., & North, N. (1993). Active and passive activation of left limbs: Influence on visual and sensory neglect. *Neuropsychologia*, *31*(3), 293–300. https://doi.org/https://doi.org/10.10160028-3932(93)90093-F

Roth, T., Sokolov, A. N., Messias, A., Roth, P., Weller, M., & Trauzettel-Klosinski, S. (2009). Comparing explorative saccade and flicker training in hemianopia: A randomized controlled study. *Neurology*, *72*(4), 324–331. https://doi.org/10.1212/01.wnl.0000341276.65721.f2

Rowe, F., Brand, D., Jackson, C. A., Price, A., Walker, L., Harrison, S., Eccleston, C., Scott, C., Akerman, N., Dodridge, C., Howard, C., Shipman, T., Sperring, U., Macdiarmid, S., & Freeman, C. (2009). Visual impairment following stroke: Do stroke patients require vision assessment? *Age and Ageing*, *38*(2), 188–193. https://doi.org/10.1093/ageing/afn230

Rowland, B. A., Bushnell, C. D., Duncan, P. W., & Stein, B. E. (2023). Ameliorating hemianopia with multisensory training. *Journal of Neuroscience*, *43*(6), 1018–1026. https://doi.org/10.1523/JNEUROSCI.0962-22.2022

Sabel, B. A., Henrich-Noack, P., Fedorov, A., & Gall, C. (2011). Chapter 13 - vision restoration after brain and retina damage: The “residual vision activation theory”. In A. Green, C. E. Chapman, J. F. Kalaska, & F. Lepore (Eds.), *Progress in brain research* (Vol. 192, pp. 199–262). Elsevier. https://doi.org/10.1016/B978-0-444-53355-5.00013-0

Schofield, T. M., & Leff, A. P. (2009). Rehabilitation of hemianopia. *Current Opinion in Neurology*, *22*(1), 36–40. https://journals.lww.com/co-neurology/fulltext/2009/02000/rehabilitation_of_hemianopia.7.aspx

Schreiber, A., Vonthein, R., Reinhard, J., Trauzettel-Klosinski, S., Connert, C., & Schiefer, U. (2006). Effect of visual restitution training on absolute homonymous scotomas. *Neurology*, *67*(1), 143–145. https://doi.org/10.1212/01.wnl.0000223338.26040.fb

Skivington, K., Matthews, L., Simpson, S. A., Craig, P., Baird, J., Blazeby, J. M., Boyd, K. A., Craig, N., French, D. P., McIntosh, E., Petticrew, M., Rycroft-Malone, J., White, M., & Moore, L. (2021). A new framework for developing and evaluating complex interventions: Update of medical research council guidance. *The BMJ*, *374*. https://doi.org/10.1136/bmj.n2061

Tiel, K., & Kolmel, H. W. (1991). Patterns of recovery from homonymous hemianopia subsequent to infarction in the distribution of the posterior cerebral artery. *Neuro-Ophthalmology*, *11*(1), 33–39. https://doi.org/10.3109/01658109109009640

Trauzettel-Klosinski, S. (2010). Rehabilitation for visual disorders. *Journal of Neuro-Ophthalmology*, *30*(1), 73–484. https://journals.lww.com/jneuro-ophthalmology/fulltext/2010/03000/rehabilitation_for_visual_disorders.19.aspx

Weiskrantz, L., Warrington, E. K., Sanders, M. D., & Marshall, J. (1974). Visual capacity in the hemianopic field following a restricted occipital ablation. *Brain*, *97*(4), 709–728. doi:10.1093/brain/97.1.709

Xing, Y., & Bai, Y. (2020). A review of exercise-induced neuroplasticity in ischemic stroke: Pathology and mechanisms. *Molecular Neurobiology*, *57*(10), 4218–4231. https://doi.org/10.1007/s12035-020-02021-1

Zhang, X., Kedar, S., Lynn, M. J., Newman, N. J., & Biousse, V. (2006). Natural history of homonymous hemianopia. *Neurology*, *66*(6), 901–905. https://doi.org/10.1212/01.wnl.0000203338.54323.22

Zigiotto, L., Damora, A., Albini, F., Casati, C., Scrocco, G., Mancuso, M., Tesio, L., Vallar, G., & Bolognini, N. (2021). Multisensory stimulation for the rehabilitation of unilateral spatial neglect. *Neuropsychological Rehabilitation*, *31*(9), 1410–1443. https://doi.org/10.1080/09602011.2020.1779754

Zihl, J. (1995). Visual scanning behavior in patients with homonymous hemianopia. *Neuropsychologia*, *33*(3), 287–303. https://doi.org/https://doi.org/10.10160028-3932(94)00119-A

Zihl, J., & Von Cramon, D. (1979). Restitution of visual function in patients with cerebral blindness. *Journal of Neurology, Neurosurgery, and Psychiatry*, *42*(4), 312–322.