Neuropsychologia 50 (2012) 1164–1177

Contents lists available at SciVerse ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Recovery from auditory and visual neglect after optokinetic stimulation with pursuit eye movements – Transient modulation and enduring treatment effects

G. Kerkhoff[a,*], I. Keller[b], F. Artinger[c], H. Hildebrandt[d,e], C. Marquardt[f], S. Reinhart[a], W. Ziegler[g]

[a] Saarland University, Clinical Neuropsychology Unit and University Ambulance, Building A.1.3., D-66123 Saarbrücken, Germany
[b] Schön Klinik Bad Aibling, Germany
[c] University of Applied Science, Faculty of Mechatronic, Karlsruhe, Germany
[d] Dept. of Psychology, Oldenburg University, Germany
[e] Dept. of Neurology, Klinikum Bremen-Ost, Germany
[f] Science and Motion, Munich, Germany
[g] EKN Entwicklungsgruppe Klinische Neuropsychologie, City Hospital Munich, Germany

ARTICLE INFO

Article history:
Received 15 April 2011
Received in revised form
14 September 2011
Accepted 15 September 2011
Available online 24 September 2011

Keywords:
Auditory
Visual
Neglect
Space
Crossmodal
Brain
Treatment

ABSTRACT

Optokinetic stimulation (OKS) modulates many facets of the neglect syndrome. This sensory stimulation technique is known to activate multiple brain regions (temporo-parietal cortex, basal ganglia, brain stem, cerebellum) some of which are involved in auditory and visual space coding. Here, we evaluated whether OKS modulates auditory neglect *transiently* and induces a sustained effect (Study 1), and whether repetitive OKS *permanently* recovers auditory neglect (Study 2). In Study 1, 20 patients with visuospatial neglect and auditory neglect in an auditory midline task following rightsided stroke were randomly allocated to an experimental and a control group matched for neglect severity and socio-demographic factors. Both groups showed a stable, pathological shift of their auditory subjective median plane (ASMP) in front space to the right side. During leftward OKS the experimental group showed a complete normalization of the shift of the ASMP, which endured until 30 min poststimulation, and returned almost to baseline values 24 h after OKS. In contrast, the control group who viewed the identical but static dot pattern, showed neither change in their ASMP during this condition, nor any significant change at 30 min or 24 h poststimulation. In Study 2, we show in two samples of neglect patients ($N = 3$ each) that repetitive leftward OKS with smooth pursuit eye movements as a therapy induces lasting improvements in auditory (the ASMP) and visual neglect while visual scanning therapy yielded no measurable effects on auditory *and* significantly smaller effects on visual neglect. In conclusion, the experiments show that a single session of OKS induces rapid though transient recovery from auditory neglect including a sustained effect after termination of stimulation, while *repetitive* OKS therapy yields enduring and multimodal recovery from auditory and visual neglect. OKS therapy with pursuit eye movements therefore represents a multimodally effective and easily applicable technique for the treatment of auditory and visual neglect.

1. Introduction

Unilateral lesions of the right cerebral hemisphere often cause a conspicuous neurological syndrome where the patient ignores visual, auditory or tactile stimuli in his contralesional hemispace, termed multimodal neglect (Karnath, Milner, & Vallar, 2002). While this syndrome may affect all modalities the deficits in the visual modality have been investigated most often and in greater detail than in the tactile or auditory modality. In audition, patients often show an ipsilesionally directed error when localizing auditory stimuli in the horizontal (left–right) axis (Bellmann, Meuli, & Clarke, 2001; Bisiach, Cornacchia, Sterzi, & Vallar, 1984; Soroker, Calamaro, Glicksohn, & Myslobodsky, 1997). In particular, patients with right *parietal* lesions show this localization deficit in auditory neglect (Bellmann et al., 2001; Clarke & Bellmann Thiran, 2004). Interestingly, spatial neglect seems to affect selectively the preattentive processing of audiospatial stimuli while that of non-spatial auditory features appears largely preserved (Deoull, Bentin, & Soroker, 2000). In contrast, lesions of the *right basal ganglia* more often tend to cause auditory extinction (Bellmann et al., 2001), although an early study by Heilman and Valenstein (1972) identified lesions of the right inferior parietal lobule in 9/10 patients with auditory extinction. This finding indicates that auditory extinction may result from lesions to different cortical areas. In auditory extinction, patients fail to report stimuli applied to the contralesional ear when simultaneously another auditory stimulus is presented to

Abbreviations: OKS, optokinetic stimulation; ASMP, auditory subjective median plane.

* Corresponding author. Tel.: +49 681 302 57380; fax: +49 681 302 57382.
E-mail address: kerkhoff@mx.uni-saarland.de (G. Kerkhoff).

0028-3932/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2011.09.032

the ipsilesional ear (De Renzi, Gentilini, & Pattacini, 1984; De Renzi, Gentilini, & Barbieri, 1989; Hugdahl & Wester, 1994; Spierer, Meuli, & Clarke, 2007). With respect to the nature of the underlying deficit, Deoull and Soroker (2000) elegantly showed that spatial localization and reporting the identity of a contralesional auditory stimulus may dissociate. Although 13 out of 14 patients in their study with auditory extinction performed at chance-level when requested to report the left-ear stimulus, the same patients performed clearly above chance when they had to report the identity (not location) of the extinguished stimuli.

As many neglect patients suffer from a poor long-term outcome due to their multiple deficits (Jehkonen et al., 2000), increasing efforts have been made in the last decade to develop novel and more effective treatments (Kerkhoff, 2003; Luauté, Rode, Jacquin-Coutois, & Boisson, 2006b). Several novel treatments based in part on earlier studies using sensory stimulation techniques, i.e. neck-proprioceptive (Schindler, Kerkhoff, Karnath, Keller, & Goldenberg, 2002) or optokinetic stimulation (Kerkhoff, 2003), or techniques for attentional modulation or sensory re-processing using prisms (Sturm, Thimm, & Fink, 2006; Kortte & Hillis, 2011) have shown that neglect phenomena can be reduced significantly by such techniques, both transiently and permanently. However, up to now most of these studies have focused on *visual* neglect phenomena (Kortte & Hillis, 2011), while the question how *auditory* neglect, or audio-spatial deficits in general can be modulated transiently or treated permanently has received little attention.

Clues to the modulation of auditory extinction or auditory neglect may be derived from two relevant studies. (Schüeli, Henn, & Brugger, 1999) assessed word identification (function words) in a dichotic listening test and found the typical right-ear advantage in a baseline condition in healthy subjects. Interestingly, during sinusoidal left-to-right rotation of the subjects in a turning chair with sudden stops this right ear advantage was no longer present because of an increased identification rate of words delivered to the left ear. This result was not due to changes of hearing sensitivitiy during chair rotation. Put differently: vestibular stimulation modulated the right-ear dominance in dichotic listening in healthy subjects. In a similar study (Hiscock, Hampson, Wong, & Kinsbourne, 1985) a diminished right-ear-advantage in dichotic listening was demonstrated due to an increase in left-ear identifications during right-to-left optokinetic stimulation (OKS) with vertical stripes in healthy subjects. Together, both studies show that vestibular or OKS stimulation modulate the left-right pattern in dichotic listening in healthy subjects, and suggest that similar effects might be obtained in patients with auditory neglect or extinction.

In recent studies using OKS we and other groups showed that repetitive optokinetic stimulation eliciting active smooth pursuit eye movements towards the contralesional hemispace leads to a substantial and lasting improvement in patients with *visuospatial* neglect (Kerkhoff, Keller, Ritter, & Marquardt, 2006a; Schröder, Wist, & Hömberg, 2008; Sturm et al., 2006; Thimm et al., 2009). With respect to the mechanisms of OKS it is known that OKS in healthy subjects activates multiple cortical and subcortical regions (temporo-parietal cortex, basal ganglia, brain stem, cerebellum (Bense et al., 2006; Dieterich, Bucher, Seelos, & Brandt, 1998; Konen, Kleiser, Seitz, & Bremmer, 2005), some of which are involved in eye movements and gaze shifts, as well as auditory and visual space coding [parietal, cf. (Schlack, Sterbing-D'Angelo, Hartung, Hoffmann, & Bremmer, 2005). In their study Schlack et al. (2005) showed largely congruent and overlapping receptive fields of neurons in the monkey's ventral intraparietal cortex for visual and auditory spatial stimuli, which enables the integration of visual and auditory information in a modality-invariant representation of external space. This finding is compatible with the multimodal (visual, auditory) deficits frequently found in neglect patients after parieto-temporal lesions (Pavani, Ladavas, & Driver, 2003). Previous studies using OKS in neglect patients have shown significant short-term modulatory effects in visual line bisection (Mattingley, Bradshaw, & Bradshaw, 1994), the subjective visual straight ahead (Karnath, 1996), visual size distortions (Kerkhoff, Schindler, Keller, & Marquardt, 1999b; Kerkhoff, 2000), visual distance judgments (Schindler & Kerkhoff, 2004), tactile extinction (Nico, 1999), tactile search (Keller, Lefin-Rank, Losch, & Kerkhoff, 2009), motor deficits (Vallar, Guariglia, Nico, & Pizzamiglio, 1997a), temporal judgments in healthy subjects (Vicario, Caltagirone, & Oliveri, 2007), and even in the mental number line in neglect (Salillas, Grana, Juncadella, Rico, & Semenza, 2009). Moreover, neurophysiological studies in awake animals indicate a significant optokinetic after-nystagmus after termination of the visual stimulation, which is related to sustained neural activity in brain-stem vestibular nuclei (Waespe & Henn, 1977). This finding indicates a significant sustained effect of OKS after termination of the stimulation and shows that OKS produces modulation effects that clearly outlive the sensory stimulation period. This in turn is a prerequisite for an effective treatment of neglect-related deficits in patients using OKS.

If OKS activates brain regions involved in the visual *and* auditory coding of space, significant modulatory effects of OKS might be expected not only for visual but also for *auditory-spatial* tasks in patients with neglect. In line with this hypothesis, it has been shown recently that auditory motion cues influence visual neglect temporarily (Golay, Hauert, Greber, Schnider, & Ptak, 2005), and that visuomotor prism adaptation reduce leftsided, neglect-related deficits in dichotic listening (Jacquin-Courtois et al., 2010). Together, these studies indicate strong cross-modal (visual–auditory) interactions in spatial neglect and suggest that OKS may modulate auditory neglect, both transiently and permanently.

In the following we describe two studies investigating the effects of OKS on auditory neglect. Study 1 evaluated whether OKS to the contralesional side induces transient recovery from auditory neglect including an early sustained effect (at 30 min) and a later sustained effect (24 h) after stimulation. Study 2 tested whether repetitive OKS as a therapy over a period of 20 sessions improves auditory and visual neglect permanently. Based on the above mentioned mechanisms of OKS we hypothesized that a single sessions of OKS may lead to a rapid though transient improvement of auditory neglect (Study 1), whereas repetitive OKS (Study 2) could lead to enduring improvements of both auditory and visual neglect.

2. Study 1: transient effects of OKS on auditory neglect

2.1. Patients and visual neglect tests

2.1.1. Patients

20 patients (Table 1), all with a single, rightsided, stroke (ischemic infarction in all cases), were recruited on the basis of the results in two visual neglect screening tests (horizontal line bisection and digit cancellation, details see (Reinhart, Keller, & Kerkhoff, 2010) *and* leftsided auditory neglect in a task assessing the auditory subjective median plane (see below) were randomly assigned (by a person not involved in the study who drew lots) to either an experimental group or a control group ($N = 10$ each). Patients in both groups did not differ significantly in neglect severity, chronicity of the brain damage, associated deficits, and socio-demographic variables (see statistics in Table 1). Informed consent was obtained from all subjects prior to inclusion in the study. All experiments performed here were conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki II.