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Rotational coherent dot movement normalizes spatial disorientation of the subjective visual vertical in patients with rightsided stroke

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ABSTRACT

Studies in healthy individuals indicate a significant influence of rotating visual motion on judgments of the subjective visual vertical (SVV). Moreover, sensory stimulation manoeuvres like *horizontal* coherent dot movement significantly modulate horizontal spatial deficits in patients with rightsided stroke. Here, we investigated whether *rotational* coherent dot movement (RCDM) modulates spatial orientation deficits of the SVV in the roll plane in right hemispheric stroke. We tested the perceptual judgment of the SVV in 20 patients with right-hemispheric, first ever stroke (10 of them with a disorder of the SVV and 10 without a disorder), and 10 healthy, age-matched subjects under three experimental conditions: (1) with a static background of small white dots, (2) with slow clockwise or (3) counterclockwise circular RCDM of these background stimuli. In the baseline condition with static background, the impaired patient group showed a counterclockwise tilt of the SVV. Clockwise RCDM normalized this deficit completely, while with counterclockwise RCDM a slight aggravation was observed. Similar but quantitatively much smaller effects were obtained in the SVV-unimpaired patients and the healthy individuals. These results demonstrate a strong modulatory effect of RCDM on the SVV in patients with a tilt of the SVV due to rightsided stroke. RCDM thus appears to influence higher spatial representations devoted to visuospatial perception of the SVV. Possible mechanisms as well as clinical implications for therapy of visuospatial disorientation (self-orientation in space) after stroke are discussed.

1. Introduction

Human spatial orientation comprises the veridical perception of the physical vertical as a fundamental ability to orient to gravity (Howard, 1982). Signs of spatial disorientation are frequent after central nervous system injury (Bronstein, 1999). In the frontal (or roll) plane, deficits in the perception of the subjective visual vertical (SVV) have been reported after a variety of lesion sites: brain stem (Dieterich and Brandt, 1993a), thalamic (Dieterich and Brandt, 1993b), and parieto-insular (Brandt et al., 1994) or parietal lesions (Cramon and Kerkhoff, 1993; Kerkhoff and Zoelch, 1998; Kerkhoff, 1999; Darling et al., 2003) all may cause pathological tilts of the SVV. The direction of this tilt is typically ipsiversive after brain stem lesions (Dieterich and Brandt, 1993a) and contraversive in supratentorial lesions, that is, counterclockwise (ccw) in patients with right hemisphere injury and clockwise (cw) in patients with left hemisphere pathology (Kerkhoff and Zoelch, 1998; Funk et al., 2013; Utz et al., 2011; Oppenländer et al., 2015). Clinically, many studies have shown significant and frequent deficits in the SVV in right hemisphere lesioned patients (De Renzi, 1982; Kerkhoff, 1999; Yelnik et al., 2002; Saj et al., 2005; Kerkhoff and Zoelch, 1998; Oppenländer et al., 2015; Utz et al., 2011; Funk et al., 2011). Such perceptual tilts of the SVV are significantly associated with balance recovery after stroke (Bonan et al., 2007) and are significantly correlated to the (poor) ambulation capacity of right hemisphere lesioned stroke patients with left neglect (Kerkhoff, 1999). Furthermore, visuospatial deficits impair functional independence (Mercier et al., 2001) and are a predictor of unfavourable functional recovery after right hemisphere stroke (Kaplan and Hier, 1982).

Many different sources of input contribute to the computation of gravity information (Howard, 1982; Bronstein, 1999). In the visual modality three types of information are important for the

Abbreviations: SVV, subjective visual vertical task (90° orientation); cw, clockwise, ccw: counterclockwise

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sense of verticality: the visual frame (i.e. a tilted rectangular frame around a vertical line), visual polarity (intrinsic up/down information of objects), and visual motion (i.e. rotational motion; cf. Howard and Childerson, 1994). Rotating visual motion (or rotational coherent dot movement, RCDM) around the fixation point influences the perception of verticality in healthy individuals (Hughes and Brecher, 1972; Mauritz et al., 1977; Howard and Childerson, 1994; Nishida and Johnston, 1999), and leads to a small torsional movement of the eyes in the direction of the roll motion (Kertesz and Jones, 1969). Despite the well-known effects of roll motion, stimulus velocity, and size of the rotating field in *healthy individuals* little is known about the effects in patients with supratentorial strokes and a pathologically tilted SVV.

The investigation of RCDM in the broader context of visuospatial perception might elucidate modulating factors, and thus lead to a better understanding of crucial mechanisms involved in pathological spatial orientation judgments, which finally could identify potential treatments for patients. Horizontal coherent dot movement is known to modulate higher order spatial cognition, such as the perception of the subjective straight ahead (Karnath, 1996), visual size estimation (Schindler and Kerkhoff, 2004), proprioceptive arm position sense (Vallar et al., 1993), and tactile perception (Nico, 1999) in patients with right hemispheric lesions. These studies have led to the emergence of novel rehabilitation techniques with active pursuit eye movements (Kerkhoff et al., 2006, 2013, 2014; Kerkhoff and Schenk, 2012). If RCDM (or roll motion) acts in a similar way on higher order spatial representations in the brain, significant modulation effects on the SVV would be expected both in patients with a tilted SVV after a right sided stroke and - to a smaller extent - also in unimpaired patients and healthy individuals. In analogy to the well-known modulatory effects of *horizontal* coherent dot movement on leftsided neglect symptoms we thus expect that the effects of RCDM should be marked in patients with a pathological tilt of the SVV but small in patients with a stroke but no tilt of the SVV. We therefore investigated in the present study the modulatory influence of RCDM on perceptual judgments of the SVV in patients with right hemisphere stroke – either with or without a tilt of the SVV - and healthy individuals. We hypothesized that i) cw roll motion normalizes the ccw tilt in the SVV task typically found in right hemisphere lesioned patients whereas ccw roll motion should aggravate this perceptual tilt slightly; ii) Healthy individuals and stroke patients without an impairment in the SVV were expected to show only small and more symmetrical shifts in the SVV towards the direction of roll motion.

2. Materials and methods

2.1. Subjects

Ten right handed (according to the German adaptation of a Edinburgh handedness inventory, Salmaso and Longoni (1985)) patients with unilateral, right hemisphere lesions (6 male, 4 female) and ten age-matched, right handed healthy individuals (6 male, 4 female) were tested (see Table 1). Selection criteria for the patients were: a) unilateral, first ever vascular (hemorrhagic or ischemic) lesion of the right cerebral hemisphere, documented by CT/MRI; b) no evidence of a brain stem lesion and no previous neurological or psychiatric disease; c) corrected binocular visual acuity of at least 0.7 (20/30 Snellen; 0.4 m viewing distance). Patients were classified into the SVV impaired group (further termed right brain damaged patients with SVV deficits, RBD+) versus the SVV unimpaired group (RBD−) based on their results in a short screening of the SVV examination prior to the begin of the experimental study. To this purpose, 5 trials with a ccw rotation

Table 1
Clinical and demographic data of 20 patients with right hemisphere stroke (10 SVV impaired, 10 SVV unimpaired).

Subject **RBD+**	Age, sex	Etiology, TSL (months)	Lesion site/volume in mm^3	Visual field sparing (°)	Motor deficit	LB	Neglect copy L/R	Cancell. L/R	Tilt in SVV (°) baseline
1	56, f	I, 8	T, P, sc/18.9	HH, 2°	Left	−8	−/+	6/1	6.5
2	44, m	I, 12	F,T,P, I/134.4	HH, 15°	Left	+9	−/+	4/1	7.2
3	48, f	H, 4	Sc/19.6	HH, 3°	–	+4	−/+	4/1	7.5
4	70, m	I, 4	F, T, P, T, sc/112.0	HH, 20°	Left	+6	−/+	5/4	3.0
5	50, f	I, 2	T, P, I, sc/87.5	HH, 15°	Left	+10	−/+	5/0	3.0
6	50, f	I, 2	T, P/30.8	–	Left	+45	−/+	23/3	9.5
7	70, m	I, 3	T, P, sc/95.2	HH, 40°	Left	+43	−/+	11/0	3.3
8	61, m	I, 3	T, sc/27.3	HH, 2°	Left	+20	−/+	16/8	3.0
9	58, m	H, 4	T, P/96.6	–	Left	+63	−/+	10/4	4.5
10	63, f	I, 3	T, P/87.5	HH, 17°	Left	+53	−/+	8/4	5.2
	Mean age: 57.0	**Mean TSL: 4.5**	**Mean volume: 80.0**	**Impaired: 8**	**Impaired: 9**	**Mean LBE: +26**	**Impaired: 10**	**Mean Om.: 9.2/2.6**	**Mean Tilt: 5.3**
RBD−									
11	57, f	I, 3	O/28.0	HH, 3°	–	−8	+/+	0/0	0.8
12	53, m	I, 2	O/2.8	HH, 3°	–	−12	+/+	0/0	2.0
13	63, m	I, 3	O/0.7	HH, 3°	–	−11	+/+	0/0	1.0
14	50, f	I,15	O/11.2	HH, 2°	–	−10	+/+	0/0	2.0
15	31, f	I, 2	O/28.0	HH, 3°	–	−2	+/+	0/0	0.5
16	45, m	I, 3	O/12.6	HH, 3°	–	−8	+/+	0/0	1.5
17	68, m	H, 2	T, BG/32.2	–	Left	+4	+/+	0/0	1.0
18	55, m	H, 7	BG/30.1	–	Left	+3.5	+/+	0/0	0.8
19	57, m	H, 7	BG/17.5	–	Left	+4	+/+	0/0	0.3
20	61, m	I, 3	T/9.8	–	Left	+2.5	+/+	0/0	0.3
	Mean age: 54.0	**Mean TSL: 4.7**	**Mean volume: 17.3**	**Impaired: 6**	**Impaired: 4**	**Mean LBE: −3.9**	**Impaired: 0**	**Mean Om.: 0/0**	**Mean Tilt: 1.0**

TSL: Time since lesion; I: ischemic; H: hemorrhagic; sc: subcortical; O/P/T/F; occipital, parietal, temporal; frontal; Visual Field Sparing (°): intact visual field (°) on the affected side. Neglect Screening Tests: LB: line bisection of a 20 cm horizontal line; the deviation from the true midline is given (in mm; +/− =right/leftsided deviation; normal cut-off: ±5 mm); Copy: copy of a star: −: leftsided omissions or size distortions, +: normal copy on right side of figure; Cancell.: cancellation of 30 numbers embedded in 200 distractors: L/R: the number of left/rightsided omissions is given; normal cut-off: 1 omission per hemifield. SVV: Subjective Visual Vertical: positive values indicate counterclockwise tilt of SVV in the initial baseline test (see text for more details).