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The influence of naturalistic, directionally non-specific motion on the spatial deployment of visual attention in right-hemispheric stroke

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ABSTRACT

An impairment of the spatial deployment of visual attention during exploration of static (i.e., motionless) stimuli is a common finding after an acute, right-hemispheric stroke. However, less is known about how these deficits: (a) are modulated through naturalistic motion (i.e., without directional, specific spatial features); and, (b) evolve in the subacute/chronic post-stroke phase. In the present study, we investigated free visual exploration in three patient groups with subacute/chronic right-hemispheric stroke and in healthy subjects. The first group included patients with left visual neglect and a left visual field defect (VFD), the second patients with a left VFD but no neglect, and the third patients without neglect or VFD. Eye movements were measured in all participants while they freely explored a traffic scene without (static condition) and with (dynamic condition) naturalistic motion, i.e., cars moving from the right or left. In the static condition, all patient groups showed similar deployment of visual exploration (i.e., as measured by the cumulative fixation duration) as compared to healthy subjects, suggesting that recovery processes took place, with normal spatial allocation of attention. However, the more demanding dynamic condition with moving cars elicited different re-distribution patterns of visual attention, quite similar to those typically observed in acute stroke. Neglect patients with VFD showed a significant decrease of visual exploration in the contralesional space, whereas patients with VFD but no neglect showed a significant increase of visual exploration in the contralesional space. No differences, as compared to healthy subjects, were found in patients without neglect or VFD. These results suggest that naturalistic motion, without directional, specific spatial features, may critically influence the spatial distribution of visual attention in subacute/chronic stroke patients.

1. Introduction

Eye movements and visual attention move together across the visual space, at least in situations where the eyes are free to move (Hunt and Kingstone, 2003). This phenomenon, often referred to as overt attention, is a fundamental behaviour during the activities of everyday life (Land, 2006). Cerebral lesions, in particular to the right hemisphere, can severely impair visual exploration and thus the spatial deployment of visual attention. Among the disorders following a right-hemispheric lesion, spatial neglect is a particularly disabling syndrome. Spatial neglect is commonly defined as a deficit in orienting towards, responding to, and reporting stimuli that are presented on the contralesional side of space (Heilman et al., 2003). In patients with acute stroke, this deficit in the spatial

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allocation of visual attention towards the contralesional space results in characteristic patterns during visual exploration. For instance, patients with neglect present a significant ipsilesional bias in the spatial distribution of visual fixations, a bias of early attentional orientation towards the ipsilesional space, frequent refixations (i.e., repeated fixations over the same region), and impaired saccade metrics (Karnath et al., 1998; Mort and Kennard, 2003; Müri et al., 2009; Niemeier and Karnath, 2000; Sprenger et al., 2002). In approximately 75% of neglect patients, patterns of visual attention allocation in space normalise within six months after stroke (Stone et al., 1992). In these patients, visual exploration is characterized by a re-orientation of visual attention towards the contralesional side, while only an early attentional bias (i.e., first saccade) towards the ipsilesional side may persist (Karnath, 1988; Mattingley et al., 1994b; Pflugshaupt et al., 2004; Pizzamiglio et al., 1992).

Several factors can influence the allocation of attention in space, and these can have a spatial or non-spatial nature. Motion, which is an omnipresent feature of visual stimuli in everyday situations, is one of those factors (Zihl, 1995). For instance, visual attention can improve when patients with neglect are instructed to look at dots on a dark background, all moving coherently towards the contralesional space (Kerkhoff et al., 2014). Furthermore, in acute neglect patients, it could be shown that moving stimuli in the contralesional space can be a spatial cue and attract visual attention (Butter et al., 1990; Mattingley et al., 1994a; Plummer et al., 2006). Nevertheless, the direction of the modulatory effect of motion seems also to depend on the integrity of the optic radiation, i.e., the presence or absence of an additional visual field defect (VFD). In a recent study, we showed that neglect patients with an additional VFD may present increased or unchanged neglect severity when confronted with motion in a touchscreen-based cancellation task (Hopfner et al., 2015).

On the other hand, patients with VFD but no neglect may show a reversed spatial bias during visual exploration, i.e., they may produce an increased number of gaze shifts towards the affected side of space (Ishiai et al., 1987; Pambakian et al., 2000). This contralesional spatial bias is thought to reflect an attempt to compensate for VFD, and seems also to increase with higher task demands (Hardiess et al., 2010).

However, to date far less is known about the effects on the spatial attentional allocation in right-hemispheric patients of motion that has no specific, directional spatial features, i.e., of naturalistic motion in everyday scenes, where elements move in both the ipsi- and the contralesional space, in heterogeneous directions.

In the present study, we thus adopted a virtual reality (VR) approach, and established an innovative setup with large projection displays. We examined free visual exploration of a virtual traffic scene, without (static condition) and with (dynamic condition) naturalistic motion, in which cars could move from the left to the right or vice versa. This not only allowed the stimulation of the full field of view (i.e., 180° as opposed to a small stimulus array, limited by the computer screen), but also the assessment of visual exploration in the extrapersonal, far space (as opposed to the peripersonal, near space, which is commonly assessed in paper-pencil and computer-based tests). Both aspects contribute to a more naturalistic and ecologically valid evaluation of the effects of motion. Furthermore, there is little knowledge about the modulatory effects of motion in patients with a subacute/chronic stroke, and about the specificity of the interactions with VFD. For this reason, in the present study, we included patients with subacute/chronic left-sided neglect and VFD and, as control groups, patients with a subacute/chronic left VFD but no neglect, and patients with right-hemispheric lesions but no neglect or VFD. Additionally, healthy subjects also performed the task.

Based on previous research, we hypothesized that the influence of naturalistic, directionally non-specific motion on the spatial allocation of visual attention would differ between patient groups and healthy subjects. In particular, we expected that, in subacute/chronic neglect patients with VFD, neglect severity would increase in the dynamic condition.

2. Methods

2.1. Subjects

Twenty-four patients who suffered from a first ischemic or haemorrhagic right hemispheric stroke (aged between 25 and 76, mean = 54.20, SD = 13.27; 8 women) and 8 healthy subjects (aged between 25 and 78, mean = 60.67, SD = 19.43; 3 women) were included in the study after giving written, informed consent. There was no statistically significant difference between patients and healthy subjects with respect to age ($t(30) = -1.019$, $p = .316$; 2-tailed) or gender ($\chi^2(1) = .046$, $p = .575$). The group of twenty-four patients was comprised of 8 patients with left-sided visual neglect and VFD, 8 patients with a left-sided VFD but without neglect, and 8 patients without any neglect or VFD. The mean interval between stroke onset and testing was 589 days (range: 28–1737 days, SD = 613). No statistically significant differences were found between the three patient groups with respect to the mean interval between stroke onset and testing ($F(2, 21) = .932$, $p = .409$), age ($F(2, 21) = .231$, $p = .796$), or gender ($\chi^2(2) = .375$; $p = .829$). The definition of the beginning of the chronic post-stroke period is variable among sources in the literature. Although some sources define the beginning of the chronic stroke period relatively late (i.e., 180 days after stroke), other sources set the beginning of this period already at three weeks after stroke (e.g., Allen et al., 2012). All patients were included in the present study at the earliest 28 days after stroke, thus overlapping with either the subacute or the chronic post-stroke phase, depending on the applied definition. In order to reflect the non-absolute nature of this definition, we opted to name the post-stroke phase with the more general term "subacute/chronic".

Since patients were in the subacute/chronic stage after stroke, neglect diagnosis was based not only on standard neuropsychological testing, but primarily on the observation of neglect manifestations in everyday behaviour. Other studies based neglect diagnosis primarily on the presence of neglect signs in computerized and/or paper-pencil tests (e.g., in at least one or two of these tests). While the present study aimed at a more naturalistic and ecologically valid evaluation of the effects of motion in neglect (and thus stressed the importance of neglect manifestations in everyday behaviour), it is to note that the definition of different criteria may lead to the inclusion/exclusion of different patients, and thus to potential differences in the results. For the assessment of neglect manifestations in everyday behaviour, the Catherine Bergego Scale was applied, which is able to quantify the influence of neglect-related persisting deficits in the activities of daily living (Azouvi, 1996; Azouvi et al., 2003). Two classes of neuropsychological tests were also administered: a cancellation task (either Bells test (Gauthier et al., 1989) or Star Cancellation test (Wilson et al.,1987)), and a line bisection task (Wilson et al., 1987). For the Bells test, we calculated the number of targets omitted on the left side minus the number of targets omitted on the right side, and the cut-off score was set at >2 (according to Azouvi et al., 2006). For the Star cancellation test, the cut-off score was set at 15% of omitted left-sided targets (according to Ferber and Karnath, 2001), i.e., 4 left-sided target omissions. For the line bisection task, a mean rightward deviation equal to or larger than 11% from the actual midline was considered as clinically relevant (according to Schenkenberg et al., 1980).

Since an evaluation of whether neglect patients also have an additional VFD is difficult to achieve with clinical confrontation testing or visual perimetry (Kerkhoff and Schindler, 1997; Müller-Oehring et al., 2003), we also assessed whether the right optic radiation was damaged or not by means of a track-wise 'hodological' lesion-deficit analysis (Thiebaut de Schotten et al., 2014), which is based on a recently published DTI atlas (Thiebaut de Schotten et al., 2011; Rojkova et al., 2016). The atlas provides the probability for each voxel in the MNI space to belong to a specific white matter tract. To conduct this analysis, we used the 'Tractotron' software (Thiebaut de Schotten et al., 2014). In a first step, we mapped the individual lesions of the patients in the structural MRI data by means of the MRIcron software (Rorden, Karnath, and Bonilha, 2007). The same procedure as in Karnath, Fruhmann Berger, Küker and Rorden (2004) and Karnath, Himmelbach and Rorden (2002) was applied: if an MRI was conducted within the 48 h post-stroke, then diffusion-weighted scans were used, otherwise T2-weighted scans were used. We delineated the boundary of the lesions directly on the individual MRI images, for each transverse slice. We then mapped the scans and the lesions into approximate Montreal Neurological Institute (MNI) space, applying the spatial normalisation algorithm provided by SPM5 (http://www.fil.ion.ucl.ac.uk/spm/). Only CT scans were available for some patients. In this case, we performed lesion mapping directly on the T1-weighted MNI single-subject template with a resolution of $1 \times 1 \times 1$ mm, as implemented in MRIcron (Rorden and Brett, 2000). Lesion mapping was performed by a collaborator who was naïve with respect to patients'