EJN fens EUROPEAN JOURNAL OF NEUROSCIENCE

European Journal of Neuroscience, Vol. 29, pp. 197–204, 2009 doi:10.1111/j.1460-9568.2008.06559.x

COGNITIVE NEUROSCIENCE

Perception of global gestalt by temporal integration in simultanagnosia

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Keywords: biological motion, global, local, simultanagnosia, spatial attention, visual perception

Abstract

Patients with bilateral parieto-occipital brain damage may show intact processing of individual objects, while their perception of multiple objects is disturbed at the same time. The deficit is termed 'simultanagnosia' and has been discussed in the context of restricted visual working memory and impaired visuo-spatial attention. Recent observations indicated that the recognition of global shapes can be modulated by the spatial distance between individual objects in patients with simultanagnosia and thus is not an all-or-nothing phenomenon depending on spatial continuity. However, grouping mechanisms not only require the spatial integration of visual information, but also involve integration processes over time. The present study investigated motion-defined integration mechanisms in two patients with simultanagnosia. We applied hierarchical organized stimuli of global objects that consisted of coherently moving dots ('shape-from-motion'). In addition, we tested the patients' ability to recognize biological motion by presenting characteristic human movements ('point-light-walker'). The data revealed largely preserved perception of biological motion, while the perception of motion-defined shapes was impaired. Our findings suggest separate mechanisms underlying the recognition of biological motion and shapes defined by coherently moving dots. They thus argue against a restriction in the overall capacity of visual working memory over time as a general explanation for the impaired global shape recognition in patients with simultanagnosia.

Introduction

Efficient visual processing not only allows the extraction of profound information such as colour, luminance or orientation, but also requires the integration of local elements into a global context. Over the past 20 years, numerous studies have investigated the mechanisms underlying these integration processes. Findings by Treisman & Gelade (1980) and computational models by von der Malsburg (for review, see von der Malsburg, 1995) suggested that complex visual arrays in which a global gestalt consists of multiple objects are represented in a master map and individual objects with similar properties 'bind together' (Kramer & Jacobsen, 1991; Kapadia *et al.*, 1995; Ferber *et al.*, 2003). Recent data not only indicated an involvement of cortical areas along the ventral visual pathway (Gilbert *et al.*, 1996; Altmann *et al.*, 2003; Kourtzi *et al.*, 2003) in visual integration processes, but also of the parietal lobe (Treisman & Gelade, 1980; Friedman-Hill *et al.*, 1995; Shafritz *et al.*, 2002).

Interestingly, patients with bilateral damage of the parieto-occipital cortex may show a selective impairment of global gestalt perception while their recognition of individual objects remains preserved. This observation has been termed simultanagnosia (Balint, 1909; Holmes, 1918; Wolpert, 1924; Luria, 1959; Rizzo & Hurtig, 1987; Friedman-Hill *et al.*, 1995; Rafal, 1997; Karnath *et al.*, 2000; Karnath, 2006) and frequently occurs in the context of Balint–Holmes syndrome. Wolpert (1924) defined simultanagnosia as 'the inability to interpret the totality of a scene despite preservation of the ability to apprehend individual portions of the whole'. As a consequence, patients with simultanagnosia can perceive only one object at a time with a 'piecemeal perception' of the remaining visual surround (Luria, 1959). The disorder is clearly distinct from visual agnosia, the inability to recognize individual objects, following damage of the ventral visual pathway largely located in the occipito-temporal cortex.

The mechanisms underlying impaired global gestalt perception are still not well understood. The perceived 'reality' might be constructed from a sequence of short impressions of individual objects (O'Reagan, 1992) requiring visual working memory to maintain visual information over time. The dorsolateral prefrontal cortex has been suggested to be involved in memory processes (Friedman & Goldman-Rakic, 1994; Jiang *et al.*, 2000) for spatial locations. Other observations indicated a critical role of sustained attention as a requirement for the efficient integration of visual information (Rizzo

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Received 15 June 2008, revised 11 October 2008, accepted 2 November 2008

& Robin, 1990). Besides a restriction of visual working memory (Coslett & Saffran, 1991; Friedman-Hill *et al.*, 1995), deficits in visuo-spatial processing (Kinsbourne & Warrington, 1962; Duncan *et al.*, 2003; Huberle & Karnath, 2006) or sustained visual attention (Rizzo & Hurtig, 1987) might thus prevent the proper binding of visual features and account for the patients' deficits. Recent findings demonstrated that global gestalt perception in patients with simultanagnosia can be modulated by the spatial distance between individual elements of hierarchical organized complex visual arrays (Huberle & Karnath, 2006) and is not *per se* disturbed. However, grouping mechanisms not only require the spatial integration of visual information, but also involve integration processes over time (Lange *et al.*, 2006). While many studies have investigated the perception of static visual scenes in simultanagnosia, it remains open if impaired global shape recognition in these patients also affects temporal integration mechanisms.

One example of perceiving global gestalt by temporal integration is with shapes defined by coherently moving dots placed in a background of randomly moving dots ('shape-from-motion'). Another example is with so-called 'point-light-walkers', representing movements via sequences of moving white dots placed at locations on invisible lines connecting the main joints of arms and legs. The latter have been used extensively to investigate the perception of biological motion, i.e. motion characterizing natural movements (Johansson, 1973; Beintema & Lappe, 2002; Casile & Giese, 2005; Troje & Westhoff, 2006). Both types of stimuli are composed of individual images that consist of local patterns that usually do not allow the identification of the respective shape or gestalt in naive observers (Cutting *et al.*, 1988; Hiris & Cramer, 2005). Only if a sequence of individual images is successfully integrated over time is the observer able to correctly identify the presented global content. To investigate whether temporal integration mechanisms are disturbed in simultanagnosia we applied 'shape-from-motion' and 'point-light-walker' movies in two patients with simultanagnosia.

Materials and methods

Subjects

Two patients with simultanagnosia and five healthy controls without a history of brain damage participated in the study, and had normal or corrected-to-normal vision. All subjects gave their informed consent for participation, which has been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and approved by the ethical committee for the Medical Board of the University of Tübingen, Germany.

Patient HW

HW, a 71-year-old, right-handed woman, was admitted to our department with a history of unspecific progressive 'visual impairment' for several years affecting several activities of daily living, such as visual orienting, reading abilities and other daily activities such as counting coins, descending stairs and cooking. Neurological examination was normal without signs of visual field deficits or involvement of other cranial nerves. Ophthalmological examination showed reduced visual acuity of the right eye (near 0.5/far 0.6) in the context of a beginning glaucoma, while normal results were obtained for the left eye (near 0.9/far 0.9).

Neuropsychological testing revealed severe simultanagnosia. The patient was not able to identify the letter at the global scale of each of 10 Navon hierarchical letter stimuli (Navon, 1977), while the recognition of the letter at the local scale remained intact. In parallel with recent findings in other patients with simultanagnosia (Huberle & Karnath, 2006), HW showed increased performance for global shape recognition at smaller inter-element distances of the letters at the local level. Further, she was not able to detect the general context of complex images of the type of the Broken Window Picture from the Stanford Binet Intelligence Test (Binet & Simon, 1905; Roid, 2003). In addition to simultanagnosia, HW showed signs of constructive apraxia that did not allow her to copy objects with increasing complexity. No signs of spatial neglect, visual agnosia or visual field defects were observed. In the Mini-Mental State Examination, HW reached 21 out of 30 points, indicating moderate cognitive impairment.

T1- and T2-weighted magnetic resonance imaging of HW showed no pathological results. An 18-fluorodeoxyglucose positron emission tomography (FDG-PET) revealed reduced metabolism in the parieto-occipital cortex bilaterally (Fig. 1). Cerebrospinal fluid analysis showed normal results for cell count and protein, but indicated decreased β-amyloid-peptide 1–42 and increased hyperphosphorylated tau-protein. This finding is frequently seen in patients with Alzheimer's disease (Jensen *et al.*, 1995; Motter *et al.*, 1995). In accordance with the recent observation of a high incidence of atypical Alzheimer's disease with hypometabolism in the parieto-occipial cortex bilaterally (Tang-Wai *et al.*, 2004), posterior cortical atrophy (PCA) was diagnosed.

Patient PNW

PNW, a 57-year-old, right-handed woman, was admitted to our department with a history of similar unspecific and progressive 'visual impairment' for several years, especially affecting activities of daily living such as her reading abilities and visual orienting. Neurological examination was normal without signs of visual field deficits or involvement of other cranial nerves. Ophthalmological examination revealed normal results.

PNW demonstrated signs of severe simultanagnosia in the consecutive neuropsychological testing. The patient was not able to identify the letter at the global scale of 10 Navon hierarchical letter stimuli (Navon, 1977), while the recognition of the letter at the local scale remained intact. Further, she was not able to detect the general context of complex pictures of the type of the Broken Window Picture. In addition to simultanagnosia, PNW showed signs of constructive apraxia and mild visual agnosia for single objects. From 10 presented real objects (pencil, pair of glasses, etc.) the patient was not able to visually identify two objects. No signs of spatial neglect or visual field defects were observed.

T1- and T2-weighted magnetic resonance imaging showed no pathological results, while FDG-PET-computed tomography (FDG-PET-CT) demonstrated reduced metabolism in the parieto-occipital cortex bilaterally (Fig. 1; note that FDG-PET was not available for PNW, but FDG-PET-CT was used instead). In parallel to HW, cerebrospinal fluid analysis indicated results concordant with mild Alzheimer's disease. As a consequence of the clinical and laboratory findings, PCA was diagnosed.

Controls

In order to exclude the possibility of a general difficulty of global gestalt perception for the stimuli applied in the present patients with simultanagnosia, we tested five healthy subjects (mean age 72 years, range 68–76 years; three males and two females) without a history of brain damage.

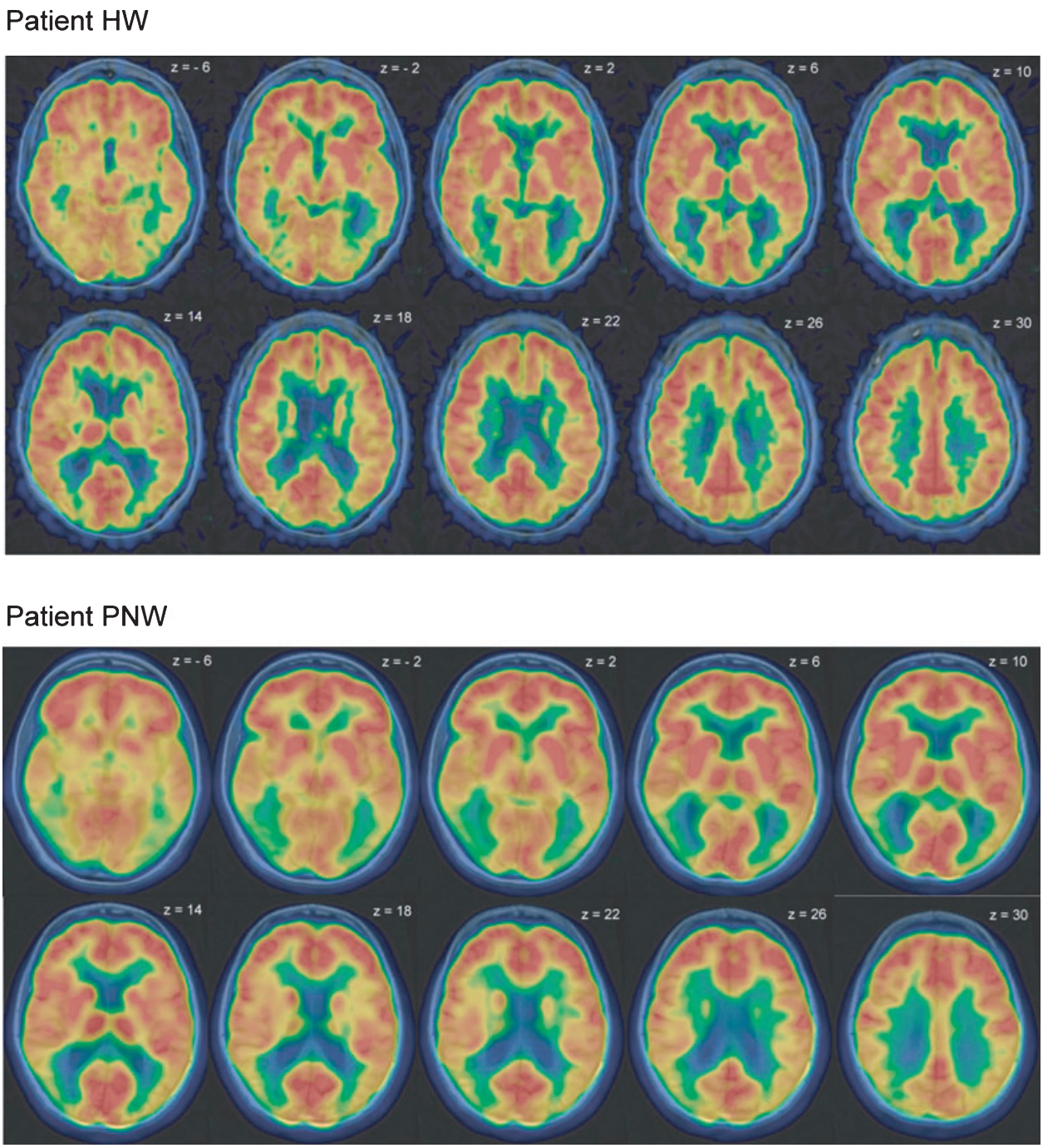

FIG. 1. FDG-PET scans for HW and FDG-PET-CT scans for PNW overlaid with the MRI scans revealed reduced metabolism in the parieto-occipital cortex bilaterally for patients HW (top) and PNW (bottom). 18-FDG metabolism is colour coded (maximum red).

Visual stimuli, design and procedure

Experiment 1 ('static')

Hierarchical organized stimuli were applied that consisted of six simple geometrical figures (arrow, cross, heart, moon, star, triangle) at the global scale, and were constructed of small circles or squares (local scale). Thus, the stimulus set consisted of 12 different stimuli. The objects at the local scale were white and presented on a black background (Fig. 2a). The local objects covered an area of 0.3° × 0.3°, while the object at the global scale covered an area of 6.2° × 6.2°. The visual angle (VA) between two neighbouring objects at the local scale was 0.9°. The presentation size for PNW needed to be increased by a factor of 1.5, which was maintained throughout all experiments.

The stimuli were presented at a viewing distance of 50 cm on a PC monitor in a darkened environment. Prior to the experiment, subjects were familiarized with the type of task as well as stimulus categories. Each trial was initiated by the experimenter when the subject attended to the centre of the PC monitor and indicated readiness. After a delay of 600 ms, the stimulus appeared for a presentation duration of 4000 ms. First, subjects were instructed to name the object at the

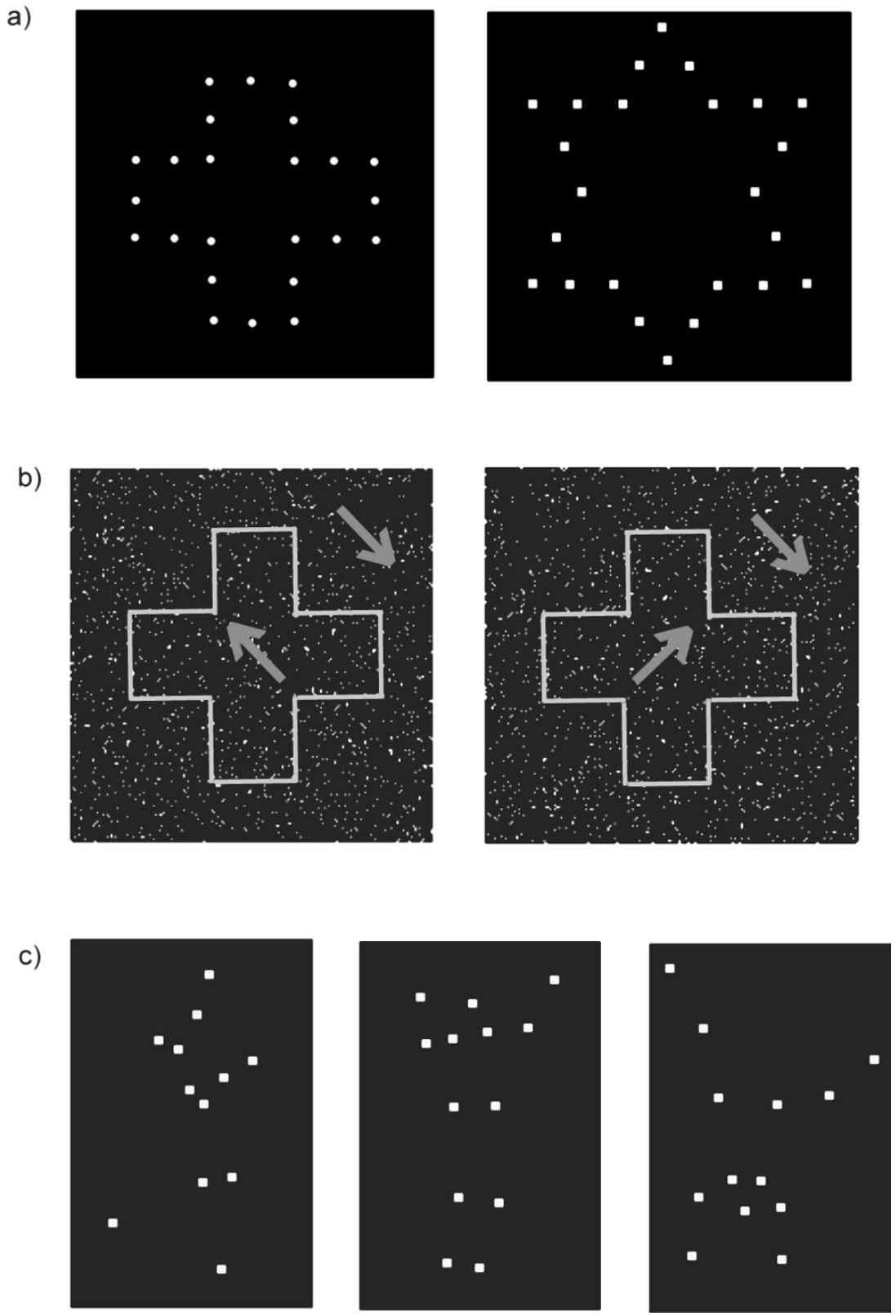

FIG. 2. Sample stimuli. (a) Displayed are two global shapes (cross, star) constructed of smaller circles (left) or squares (right). (b) Displayed is one global shape (cross) that consists of coherently moving dots with a direction of motion rotated 45° counterclockwise (left) or clockwise (right) from the vertical axis presented on a background of coherently moving dots rotated 45° counterclockwise from the vertical axis ('shape-from-motion'). (c) Displayed are three examples (running, jumping, turning a cartwheel) of the human movements used in the experiment. Stimuli consisted of white dots placed at locations on (invisible) lines connecting the main joints of upper arm, forearm, upper leg and lower leg, and were presented on a black background ('point-light-walkers').

global scale of each stimulus (global task). The experimenter coded the verbal response given by the subject. All objects at the global scale were presented in a balanced order and repeated 10 times with an equal number of repetitions for the object at the local scale, resulting in a total number of 60 trials. Subsequently, the same block of stimuli was presented while the subjects named the object at the local scale (local task). Because the perception at the local scale is preserved in simultanagnosia, we used the shortest presentation duration that allowed correct local identification (HW 1000 ms, PNW 2000 ms).

Because PNW showed signs of mild visual agnosia, we had to exclude impaired recognition of the objects (geometrical figures, see above) presented in the experiment. In addition to the 'static' experiment, we therefore tested the patient's ability to identify the objects when their outline was presented as a white line drawing or when the entire shape was displayed in white on a black background. Each geometrical figure was presented 10 times in a randomized order with an equal number of repetitions for the two different kinds of stimuli, resulting in a total number of 60 trials. PNW performed 76.7% correct, indicating perception of the figures well above chance level.

Experiment 2 ('motion')

First, hierarchically organized stimuli were applied that consisted of the geometrical figures used in Experiment 1. These shapes were defined by coherently moving dots (Fig. 2b) that moved in a linear direction 45° to the left or right of the (invisible) vertical axis presented on a background of coherently moving dots rotated 45° counterclockwise from the vertical axis, resulting in 12 different stimuli ('shape-from-motion'). We used an average of 10 dots per degree VA with an individual size of one pixel and a speed of 0.91° VA/s for the object as well as the background. Each static image was presented for 40 ms and combined to a movie of 4000 ms for all geometrical figures. In the second part of Experiment 2, subjects were presented with six different movies of complex motion patterns representing human movements ('biological motion': walking, jumping, swimming, crawling, turning a cartwheel, playing soccer). These stimuli were derived from recordings with a body tracker (ascension motion star) of the joint positions of one human actor performing these movements. For the stimulus display, white dots were placed on each of the main joints of the body (shoulders, elbows, hands, hips, knees and ankles) and the head, and presented on a black background (Fig. 2c). Each static image was presented for 40 ms and combined to a movie of 2000 ms that was repeated twice without delay, resulting in a final movie of 4000 ms for each of the six movements.

In addition, we tested patient HW in a control condition that used a modified version of the geometrical figures of Experiment 1. The stimuli consisted of the squares used for 'biological motion', that moved clockwise or counterclockwise along the contour of the shape with a speed of 0.91° VA/s ('shape-from-motion control').

All stimuli of Experiment 2 covered an area of $6.2 \times 6.2°$. The presentation procedure of Experiment 2 was identical to Experiment 1, with a total number of 60 trials for each stimulus category. Subjects had to identify the global shape ('shape-from-motion') or the human movement ('biological motion'). In parallel to Experiment 1, the presentation size was increased for PNW by a factor of 1.5.

Controls

All healthy subjects were tested in Experiments 1 and 2 with the protocol used for HW.

Results

We computed the average percent of correct responses across conditions and tasks for each experiment. Performance above chance level was defined by applying the 95% confidence interval for the binomial distribution, respectively (global task of 'static' and 'motion' experiment: number of trials = 60, chance level = 1/6; local task of 'static' experiment: number of trials = 60; chance level = 1/2).

Controls

The performance of healthy subjects was very close to perfect for both experiments, reaching 100% correct responses in Experiment 1 independent of the task and 99.0% in Experiment 2 for 'shape-from-motion', 99.7% for 'biological motion' and 99.7% for 'shape-from-motion control'.

Patients HW and PNW

Experiment 1 ('static')

In parallel to other patients with simultanagnosia, HW and PNW showed a severe impairment of global shape recognition for static stimuli, while object identification at the local scale of these stimuli was largely preserved (Fig. 3a).

Experiment 2 ('motion')

Besides a severely impaired perception of static global shapes, HW and PNW also showed disturbed global gestalt perception when shapes were defined by coherently moving dots (Fig. 3b). Statistical analysis indicated no differences in the performance for global gestalt perception between the global task of Experiment 1 and 'shapes-from-motion' (HW, $\chi^2 = 0.75$, $P = 0.39$; PNW, $\chi^2 = 0$, $P = 1$). In clear contrast, the ability to perceive biological motion was well above chance level in both patients (Fig. 3b). Statistical analysis suggested significantly higher performance compared with the global task in Experiment 1 (HW, $\chi^2 = 28.42$, $P < 0.01$; PNW, $\chi^2 = 25.15$, $P < 0.01$) and 'biological motion' (HW, $\chi^2 = 20.89$, $P < 0.01$; PNW, $\chi^2 = 25.15$, $P < 0.01$).

In addition, HW showed disturbed global gestalt perception when shapes were defined by local squares that moved along the contour of the shape ('shape-from-motion control'; Fig. 3b).

Discussion

The present study addressed integration mechanisms over time in two patients with simultanagnosia. We first tested the patients' ability to recognize static hierarchically organized global shapes that were constructed from smaller objects. In parallel to a number of earlier studies (Balint, 1909; Holmes, 1918; Wolpert, 1924; Luria, 1959; Rizzo & Hurtig, 1987; Friedman-Hill *et al.*, 1995; Rafal, 1997; Karnath *et al.*, 2000; Valenza *et al.*, 2004; Tang-Wai *et al.*, 2004; Huberle & Karnath, 2006), we observed a severe impairment of global gestalt perception, while the recognition of individual objects at the local level remained unaffected. When we tested the patients' ability to recognize shapes by temporal integration, we found disturbed perception of global shapes defined by coherently moving dots ('shape-from-motion') and objects that moved along the contour of the global shape ('shape-from-motion control'), while the temporal integration for biological motion was largely preserved.

Our findings thus argue against the assumption of a general impairment of temporal integration mechanisms in simultanagnosia.

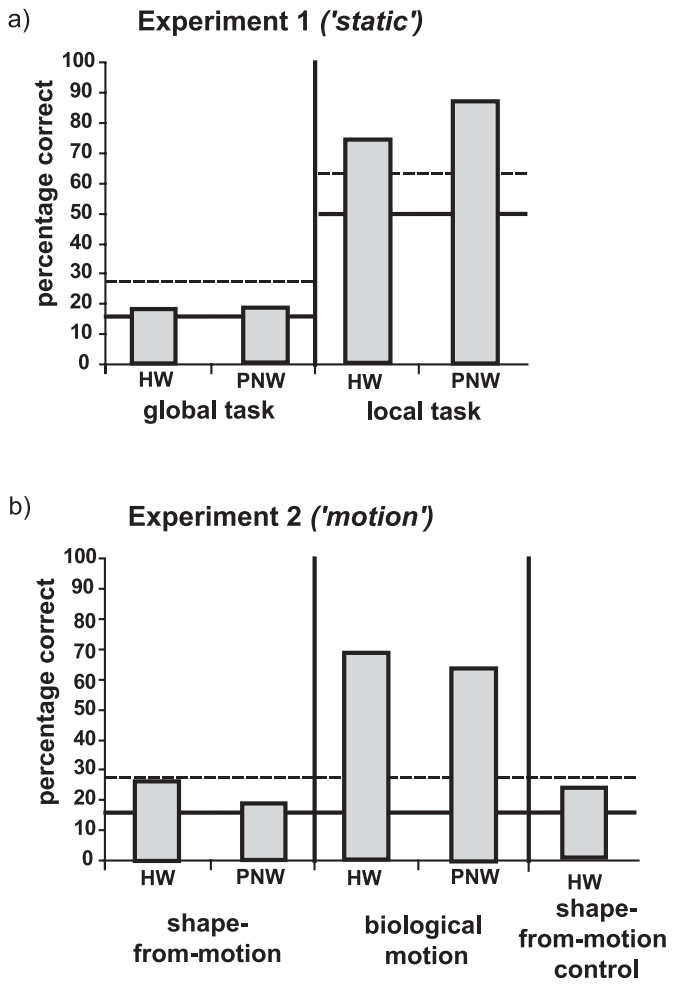

FIG. 3. Average percentage of correct shape recognition for patients HW and PNW with simultanagnosia in (a) Experiment 1 ('static') and (b) Experiment 2 ('motion'). The solid lines indicate chance level (16.7% for the global recognition tasks; 50% for the local recognition task), and the dashed lines the binomial 95% confidence interval of chance level.

The data suggest that the perception of 'shape-from-motion' stimuli is not only disturbed when the global shape is defined by coherently moving dots but also for motion patterns, that are similar to the displays used for the 'point-light-walker' stimuli.

What is known about the anatomical representation of global shapes defined by motion coherency on the one hand and biological motion on the other? A dissociation of biological motion perception from motion coherency, shape-from-motion and general motion perception were reported previously for motion-impaired patients (Vaina *et al.*, 1990; McLeod *et al.*, 1996). These patients were severely impaired in many tasks that relied on basic motion detection, but not in form discrimination tasks. Further, evidence has been reported for spared perception of biological motion in the context of impaired perception of general motion in children with William's syndrome (Jordan *et al.*, 2002). On the other hand, perception of biological motion may be impaired when general motion and form perception are intact (Cowey & Vaina, 2000). In line with previous findings, our data suggest separate integration mechanisms for the perception of motion coherency and biological motion in the human brain.

Local motion contrast in the monkey brain is detected by neurons in the middle temporal (MT) and medial superior temporal cortex (Newsome *et al.*, 1985; Newsome & Pare, 1988) with a homologue in the human brain known as the human motion complex (hMT/V5+; Tootell *et al.*, 1995; Schenk & Zihl, 1997a,b). 'Featural dissimilarity' implemented by centre-surround antagonism of neurons in the MT might serve as a basis for relative motion tuning likely allowing figure ground segmentation (Albright & Stoner, 1995; Bradley & Anderson, 1998; Grunewald *et al.*, 2002), and has been demonstrated to be modulated with the percept (Grunewald *et al.*, 2002; Krekelberg & Albright, 2005) and attentional mechanisms (Thornton & Kourtzi, 2002; Cook & Maunsell, 2004). Besides motion-sensitive areas, centres in the occipito-temporal cortex that have been linked with the processing of shape information seem to be involved in the recognition of global shapes defined by motion (Altmann *et al.*, 2004). However, the visual system not only shows efficient processing of 'shapes-from-motion', but also biological motion defined by point-light-walkers. One example can be found in the observation that humans are able to distinguish different movement patterns at short presentation times of 400 ms (Johansson, 1976). While the perception of 'shapes-from-motion' seems to be represented in the human motion complex and higher visual areas of the ventral visual pathway, processing of biological motion has been associated with additional neural structures. Single-cell recordings and (functional) brain imaging indicated specialized areas for the perception of biological motion in the anterior superior temporal sulcus (STSa) and superior temporal gyrus (STG) predominantly of the right hemisphere (Perrett *et al.*, 1985; Posner & Dehaene, 1994; Grossman *et al.*, 2000; Puce & Perrett, 2003). This hypothesis was supported by lesion data in humans (Vaina *et al.*, 2001; Akiyama *et al.*, 2006). Thus, it seems possible that the (relatively) more posteriorly located neural structures involved in the processing of 'shapes-from-motion' were affected by the lesions in the present patients, while the STSa/STG remained largely intact, which enabled the patients to perceive biological motion.

Alternatively the robustness of biological motion perception in these patients may be explained if biological motion perception is not derived from motion analysis but from the analysis of body form over time (Lange *et al.*, 2006). However, our patients were impaired in global form analysis, whether derived from motion ('shape-from-motion') or from the binding of small objects into a global shape (Experiment 1). Thus, the preserved perception of biological motion might indicate that the binding of the local dots of a 'biological motion' stimulus into a global gestalt is a different, and more immediate, process than general shape perception. This suggests that there may be a specialized processing scheme for biological motion. Such a processing scheme could involve a direct match of light points onto specialized templates of the human form (Lange *et al.*, 2006) rather than a bottom-up integration of features, or the use of particular aspects of the local motion signals of the points (Casile & Giese, 2005; Troje & Westhoff, 2006).

What could be the possible mechanisms underlying simultanagnosia that might explain the present findings? Recent work has suggested that grouping mechanisms and the processing of motion over time are maintained over time by visual working memory with a limited capacity (Thornton & Kourtzi, 2002; Saiki & Miyatsuji, 2007), while others suggested an involvement of visuo-spatial attention (for review, see Croner & Albright, 1999). Interestingly, recent findings suggested that the processing of biological motion interacts with visuo-spatial attention (Schenk & Zihl, 1997a,b; Cavanagh *et al.*, 2001; Thornton *et al.*, 2002; Pavlova *et al.*, 2006) and is not an attention-independent mechanism. If a restriction in the capacity of visual working memory over time was the critical mechanism underlying simultanagnosia, decreased recognition performance would have been expected not only for the perception of 'shapes-from-motion' but also 'biological motion'. Our results thus rather support the role of visuo-spatial attention underlying the disturbed global gestalt perception in simultanagnosia and argue against visual

working memory as the critical mechanism. In this context, it should be noted from the results of Experiment 2 that visuo-spatial perception required for the perception of biological motion does not necessarily allow normal global gestalt perception.

Over the past decade, Tang-Wai *et al.* (2004) reported the largest number of patients with PCA, collected from two dementia centres over a period of 14 years. Twenty-eight of these 40 patients showed signs of simultanagnosia. *Post-mortem* histopathological investigation of nine patients demonstrated the presence of Alzheimer's disease in seven brains and, compared with patients with 'typical' Alzheimer's disease, an increased number of neurofibrillary tangles and senile plaque in the parieto-occipital cortex (Tang-Wai *et al.*, 2004). In the course of the disease, patients with 'typical' Alzheimer's disease frequently exhibit signs of impaired higher visual functions with an involvement of more posterior located brain areas. Recently, patients with Alzheimer's disease (compared with healthy controls) have been shown to perform worse on contour detection with a pronouncement in patients with Alzheimer's disease with atrophy of the occipital lobe likely underlying a loss of long-range spatial interactions (Uhlhaas *et al.*, 2008). It might be discussed whether PCA should be better seen in the context of Alzheimer's disease, presenting a parieto-occipital onset. The present study did not aim to investigate differences between the different manifestations or stages of Alzheimer's disease. Thus, we can not and also did not aim to answer the question whether or not patients with 'typical' Alzheimer's disease show the same impairment compared with patients with PCA.

Finally, simultanagnosia might also be observed in patients with acute brain damage due to bilateral temporo-occipital stroke. In the present study, we were not in the position to also test a patient with simultanagnosia due to such latter aetiology. Thus, it must remain an issue of future research to investigate whether the results obtained in the present study of two patients with simultanagnosia due to PCA can be generalized to patients with simultanagnosia following stroke aetiology. Further, the small sample size of two patients with simultanagnosia included in the present study also might raise the question of generalization. The highly similar pattern of results across both patients and experiments argues in favour of a generalization but, of course, this needs to be handled with care until more subjects have been investigated.

In conclusion, we observed that coherently moving dots representing the main joints of a human body allowed largely intact perception of human movements in patients with simultanagnosia, while the integration of global shapes defined by coherently moving dots was disturbed. Our findings suggest separate mechanisms underlying the recognition of biological motion and shapes-from-motion. Thus, they argue against a restriction in the overall capacity of visual working memory over time as a general explanation for the impaired global gestalt perception in our patients with simultanagnosia.

Acknowledgements

This work was supported by a grant of the Bundesministerium für Bildung und Forschung (BMBF-Verbund 01GW0654 'Visuo-spatial cognition'). The authors would like to thank Marc Himmelbach and Johannes Rennig for help with Fig. 1.

Abbreviations

FDG-PET, 18-fluorodeoxyglucose positron emission tomography; FDG-PET-CT, 18-fluorodeoxyglucose positron emission-computed tomography; MT, middle temporal; PCA, posterior cortical atrophy; STG, superior temporal gyrus; STSa, anterior superior temporal sulcus; VA, visual angle.

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