Neurocase (2002) Vol. 8, pp. 296–305

Agnosia for Object Orientation: Naming and Mental Rotation Evidence

Oliver H. Turnbull, **Sergio Della Sala**[1] and **Nicoletta Beschin**[1,2]

Centre for Cognitive Neuroscience, School of Psychology, University of Wales, Bangor, [1]Neuropsychology Group, Department of Psychology, University of Aberdeen, Aberdeen, UK and [2]Department of Rehabilitation, Somma Lombardo Hospital, Gallarate, Italy

Abstract

We have previously reported the performance of a patient (NL) who could recognize objects, but appeared to lack knowledge of their orientation. These results were interpreted as evidence that NL had isolated access to a viewpoint-independent (ventral stream) object recognition system. However, because NL's responses on naming tasks were not timed, it was not possible to establish whether he showed the same pattern of reaction time performance generally accepted as evidence of a 'mental rotation' strategy in neurologically normal subjects. Here we report NL's performance on two reaction time tasks, testing his ability to transform images when naming, and discriminating between rotated mirror image objects. As predicted, and in contrast to normal volunteers, NL showed no 'mental rotation' effect in his naming of misoriented objects. Paradoxically, he performed well on a traditional Shepard and Metzler mental rotation task. He also showed a normal orientation effect when dealing with misoriented faces. These findings offer further support for viewpoint-independent theories of object recognition, and bolster the claim that object orientation knowledge can be regarded as, in some respects, a special class of spatial information.

Introduction

There has been a long-standing argument about the mechanism by which objects are recognized across multiple viewpoints (Pinker, 1984; Logothetis and Sheinberg, 1996). Perhaps the most intuitive solution is the proposal that misoriented objects are aligned by a process of analogue imagery transformation (i.e. mental rotation) so that the image matches a standard (canonical) model in memory (Jolicoeur, 1985, 1990). However, it has also been suggested that objects might be recognized by a mechanism which is independent of the viewpoint of the observer (except under extreme circumstances) (Marr, 1982; Biederman, 1987). There is a reasonable body of evidence to support both the transformation and the viewpoint-independent proposals. Indeed, it appears that both approaches may be employed, each under different circumstances (Logothetis and Sheinberg, 1996; Turnbull *et al.*, 1997b).

Recently, this debate has extended to include the issue of which brain regions participate in various aspects of the object recognition process, particularly in the context of the 'two cortical visual systems' account (Ungerleider and Mishkin, 1982). It is widely accepted that object recognition depends upon the structures of the occipitotemporal lobe: the ventral of the 'two cortical visual systems'. It has also been argued that this system uses a viewpoint-independent mechanism to achieve recognition (Kosslyn *et al.*, 1990, 1994; Biederman and Gerhardstein, 1993; Milner and Goodale, 1995). However, this account fails to accommodate the evidence (e.g. Jolicoeur, 1985) that objects might (at least on some occasions) be recognized using a 'mental rotation' strategy. It also fails to acknowledge that patients with lesions in the inferior parietal lobule (i.e. outside the ventral stream) show deficits in object recognition for stimuli presented from 'unusual views' (Warrington and Taylor, 1973). Moreover, patients with inferior parietal lesions also show disorders of mental rotation (Farah and Hammond, 1988; Morton and Norris, 1995). In order to account for these data, it has been argued (Turnbull *et al.*, 1997b) that the ventral object recognition system can also tap an additional resource, involving the structures of the inferior parietal lobule [Milner and Goodale's (1995) 'third' stream]. This mechanism would only be employed under 'non-optimal' circumstances, such as recognizing objects from unusual views, or on occasions where object parts were occluded, seen under unusual lighting, etc.

A central part of the argument linking viewpoint-independent recognition with the ventral stream has been the findings

Correspondence to: Oliver Turnbull, Centre for Cognitive Neuroscience, School of Psychology, University of Wales, Bangor LL57 2AS, UK.
Tel: +44 (0)1248 383670; Fax: +44 (0)1248 382599; e-mail: o.turnbull@bangor.ac.uk

of a series of neurological patients who are able to achieve object recognition while lacking knowledge of the orientation of objects. The most dramatic feature of their performance has been the tendency of such patients to rotate their drawings of objects through 90 or 180° (Solms *et al.*, 1988, 1998; Turnbull *et al.*, 1995, 1997a, b; Turnbull, 1996). They also make frequent errors in choosing the correct orientation of objects (Turnbull *et al.*, 1995, 1997a), and in choosing the misoriented object in an odd-one-out task (Turnbull *et al.*, 1997a). In a related finding, other patients with apparently normal object recognition abilities failed to discriminate between the object and its mirror image (Riddoch and Humphreys, 1988; McClosky *et al.*, 1995; Turnbull and McCarthy, 1996a; Lambon-Ralph *et al.*, 1997).

Most of these patients had suffered lesions in the territory of the middle cerebral artery, perhaps more common on the right than the left side (Turnbull *et al.*, 1995, 1997a; Turnbull, 1996; Solms *et al.*, 1998), and a common feature of most cases has been the involvement of the parietal (or frontal) lobes (Solms *et al.*, 1988; Turnbull *et al.*, 1995, 1997a; Turnbull, 1996). Consistent with this, most patients presented with 'spatial' deficits—constructional apraxia, neglect, left–right disorientation, etc. Visual object agnosia or other signs of 'ventral stream' lesions, were notably absent. On the basis of these findings we have argued (Turnbull *et al.*, 1997b) that the presence of intact object recognition, together with dramatic errors of object orientation, suggest that these patients have access to a relatively normal ventral object recognition system, employing a viewpoint-independent mechanism. However, the lesion had isolated this system from the more dorsal visual systems, which have access to information about the veridical spatial properties of the visual object. This separation of function between visual systems leads to the unusual situation where such patients can recognize objects, but are unable to know which way up they normally lie, i.e. an 'orientation agnosia' (Turnbull *et al.*, 1997a).

One potentially important feature of the testing of these patients (Solms *et al.*, 1988, 1998; Turnbull *et al.*, 1995, 1997a, c; Turnbull, 1996) has been that (as in most investigations of neurological patients) the testing has allowed unlimited viewing and response time when recognizing objects. It might be suggested, for example, that the dissociation between orientation and identification in these patients was an artefact of the patients having profound difficulties in integrating together elementary features from the visual array. This account is reminiscent of the case of some visually agnosic patients who correctly recognized objects after several attempts at piecemeal reconstruction of object structure (Farah, 1990; Grusser and Landis, 1991). If this was the case, the performance of these patients could no longer be interpreted as the involvement of the normal operation of an 'isolated' ventral visual system.

Thus, it would seem appropriate to collect reaction time responses from such patients on naming and spatial tasks—although such data are not always easy to collect reliably from neurological patients. These data would make it possible to establish whether the patient's performance showed the same temporal features as volunteers who act as controls. Such findings are especially appropriate in the present circumstances, because normal subjects show a characteristic pattern of linearly slowed reaction time performance as a function of picture–plane misorientation (at least up to 120°; Jolicoeur, 1985). Our proposed explanation of the cause of agnosia for object orientation suggests that this effect would be absent in such patients (Turnbull *et al.*, 1997a). It has been possible to collect reaction time measures on a naming and a spatial task from one of the patients who had previously been reported—patient NL (Turnbull *et al.*, 1997a). These data are reported below.

Case report

NL, a 67-year-old right-handed man, had suffered an ischaemic stroke in the right anterior parietal lobe which produced a pronounced left hemiparesis. A full history and neuropsychological assessment of NL have been reported elsewhere (Beschin *et al.*, 1997; Turnbull *et al.*, 1997a). Briefly: he showed no difficulty on tests of abstract reasoning, calculation, and long-term verbal memory. He showed no features of perceptual neglect, although he did show a left visuospatial neglect specific to imagery (Beschin *et al.*, 1997). NL's performance on a range of perceptual tasks also demonstrated that he was able to derive a good deal of information about object structure. For example, he performed well on tasks of visual short-term memory (Corsi blocks; Turnbull *et al.*, 1997a) and a test of constructional praxis (Turnbull *et al.*, 1997a). He was able to recognize correctly a set of 32 drawings from the Snodgrass and Vanderwart (1980) corpus (Turnbull *et al.*, 1997a).

However, his accurate spatial knowledge was markedly disrupted in terms of object orientation. Thus, he was able to copy a wide range of types of line drawing with great accuracy (Turnbull *et al.*, 1997a), but tended to draw them rotated relative to the original—typically by 90 or 180° [see Turnbull *et al.* (1997a, pp. 158–161) for a systematic investigation of this issue]. A prominent feature of NL's performance was a tendency to rotate figures in copying tasks, for example the Rey figure, a figure from the Mini Mental State Examination (MMSE), several custom-designed mini-Rey figures, and several drawings from the Snodgrass and Vanderwart (1980) corpus (Turnbull *et al.*, 1997a). He also showed a preference for hanging the pictures in his hospital room upside down (Turnbull *et al.*, 1997a). However, apart from these gross errors of orientation, his spatial abilities seemed remarkably intact. His rotated drawings maintained the structural integrity of the figure and the relative position of component parts—so that NL showed far less 'constructional apraxia' than other patients with agnosia for object orientation (Turnbull, 1996; Turnbull *et al.*, 1995, 1997a, b; Solms *et al.*, 1998).

In addition to errors of rotation in copying drawings, NL also made errors when he was asked to provide purely verbal answers to orientation questions. He could provide the correct orientation for only 15/32 Snodgrass and Vanderwart (1980) drawings, although he correctly named all 32 (cf. Turnbull *et al.*, 1995). NL was also given a series of tasks in which he was required to choose the odd-one-out of three items. Consistent with his problems in establishing object orientation, he was correct on only 17/50 (chance = 16.7) of the items in which the target differed only by a 180° picture–plane rotation, and scored only 21/50 (chance = 16.7) on a matched task in which the target differed by a mirror image. In contrast, he scored 41/50 (chance = 16.7) on a matched control task where the target differed by a minor structural change (Turnbull *et al.*, 1997a).

Comment

NL's performance on a range of perceptual tasks has demonstrated that he is able to derive a wide range of types of information about object structure with great accuracy. Thus, it appears that NL has intact object recognition, together with an inability to extract orientation information about the objects which he can recognize.

Experimental investigations

Task 1. Naming of picture–plane misoriented drawings

When asked to name picture–plane misoriented drawings, normal subjects show a linear increase in reaction time performance as a function of stimulus orientation (at least up to 120°; Jolicoeur, 1985, 1990). The effect is substantial on the first exposure to any given exemplar (the 'first trial' effect), while a smaller effect remains on subsequent trials (Jolicoeur, 1985, 1990; Tarr and Pinker, 1989; Logothetis and Sheinberg, 1996). This finding has been interpreted as evidence for an analogue transformation (i.e. mental rotation) approach to recognizing misoriented objects, and has been shown even at the individual subject level in neurological patients (Turnbull and McCarthy, 1996a). We have argued elsewhere (Turnbull *et al.*, 1997a, b) that NL's poor performance on tasks of orientation suggests that he should not employ such a method, and instead a mechanism which is viewpoint-independent. Given this argument, NL should show no effect of orientation on his reaction time performance when naming objects.

Stimuli. The stimuli were based on 20 line drawings taken from the Snodgrass and Vanderwart (1980) corpus. All objects had a clear canonical upright. The objects were: aeroplane, bear, camel, car, cat, chair, cup, dog, duck, eagle, hat, frog, kangaroo, lamp, motorbike, piano, rabbit, shoe, tortoise and trumpet. The stimuli appeared at each of six orientations: 0, 60, 120, 180, 240 and 300°, and were presented in blocks of 60 trials.

Procedure. Testing was carried out using a Macintosh Powerbook 520c, using Superlab software. The stimuli were presented sequentially, in randomized order, in the centre of the screen, and remained there until the subject responded (verbally) by naming the target. The 60-trial block was presented four times (i.e. 240 items), in the same test session, with a brief rest break between blocks. Four volunteers with no known neurological diseases, aged 57, 59, 62 and 71 years, also performed the task.

Results. Three of the control subjects made no errors, one subject made 2/240 errors. NL's naming performance was also very good. He made only 1/240 clear naming error (starting to name car as 'aeroplane', before correcting himself). In addition, he regularly made a superordinate classification on one item—consistently naming eagle as 'bird' (although on a single occasion he responded 'a small bird, yes an eagle'). All incorrect responses, and outlying reaction times (greater than two standard deviations) were removed from latency analyses. In the case of NL, this involved removing 6.3% of the reaction time data. For the controls, this involved removing between 0.4 and 1.4% of the reaction time data.

All of the control subjects showed a linear increase on response latency as a function of orientation, with r^2 values ranging between 0.44 and 0.93 (see Fig. 1). The slope of this function was consistent across subjects (varying between 0.61 and 0.69 ms/°). In contrast, NL's performance did not show an increase in reaction time as a function of orientation. In fact the slope showed a marginal decrease at –0.29 ms/°, and there was no relationship between orientation and latency ($r^2 = -0.10$). There were insufficient error data, either from NL or the controls, to consider an analysis of accuracy performance.

To determine whether NL's latency performance was different from that of the controls, a method (and accompanying computer program) described by Crawford and Howell (1998) was used. Fisher's z-transformation was applied to the correlations between orientation and response latency, based on the mean and standard deviation of the four control correlations. Crawford and Howell's program was used to carry out a modified independent samples t-test, comparing the controls' mean correlation with NL's. The test differs from a standard t-test in that $n = 1$ in one of the samples, and hence this sample does not contribute to the estimate of within-group variance (Sokal and Rohlf, 1981). This procedure revealed that the relationship between orientation and latency, in the case of NL, was significantly different from that of the controls ($t_{(3)} = 2.63$, $P < 0.05$). Similarly, the slope, in the case of NL, was significantly different from that of the controls ($t_{(3)} = -24.7$, $P < 0.001$).

Because one should perhaps be hesitant in interpreting a negative finding (i.e. the fact that NL's data show no relationship between orientation and latency is interesting), a series of split-half reliability analyses were also performed on the data. The first compared the performances of the first

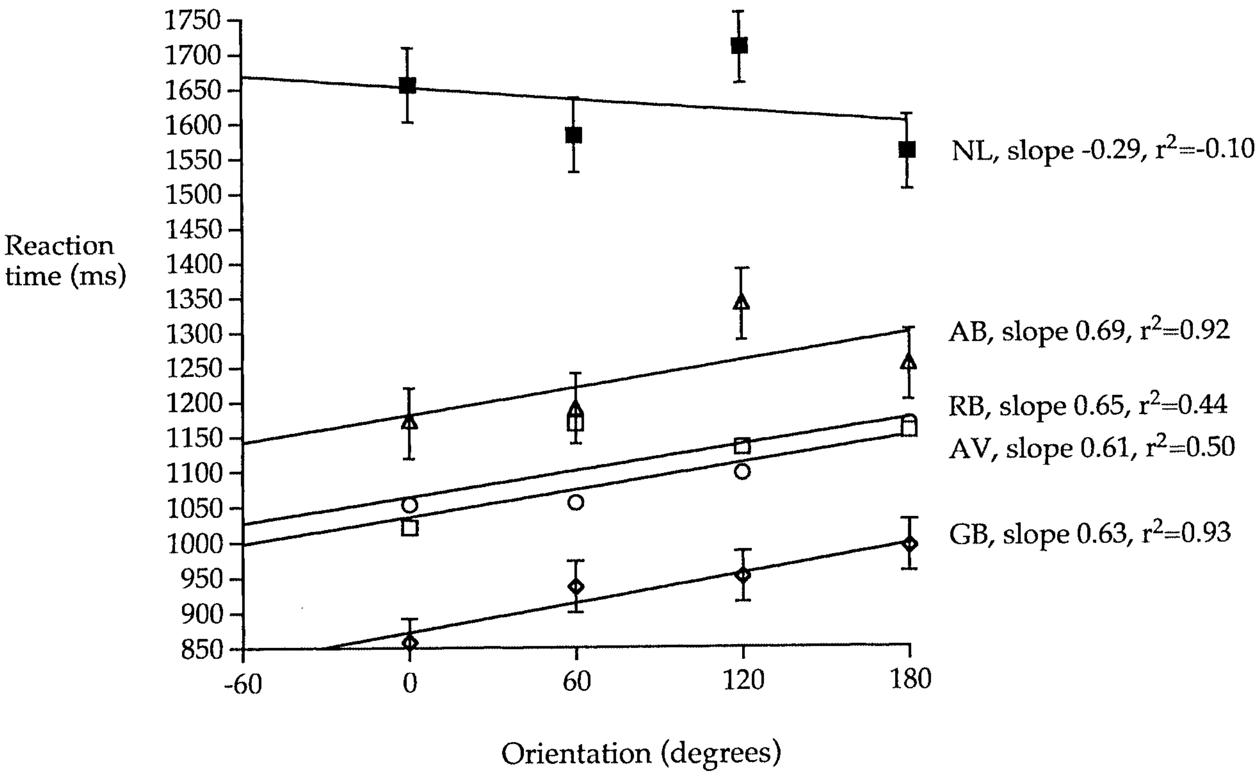

Fig. 1. Performance of NL and the control subjects on a naming task. Data from 240 and 300° have been collapsed on to the 120 and 60° findings to simplify interpretation. Error bars represent one standard deviation, and are included for NL and the controls with the greatest (GB) and least (AB) variance.

50% with the second 50% of data for each subject. In the case of NL, these data were consistent with the overall findings. For the initial 50% of trials the slope was –0.07, which was significantly different from that of the controls (who had slopes of 0.96, 1.02, 0.89 and 1.63; $t_{(3)} = -3.13$, $P < 0.05$). For the second 50% of trials the slope was –0.39, which was again significantly different from that of the controls (who had slopes of 0.43, 0.21, 0.36, and 0.29; $t_{(3)} = -6.76$, $P < 0.01$). Thus, while the controls consistently show a positive slope across the split-halves, NL consistently does not.

To quantify the reliability of the data at the individual subject level, the slopes of the two subsets of data (i.e. first 50% and second 50%) were correlated for each subject. This provides a measure of the reliability of any individual subject's performance. The strength of NL's correlation ($r^2 = 0.30$) was not significantly different from that of the controls (0.24, 0.34, 0.35 and 0.42; $t_{(3)} = -0.45$, $P > 0.05$). Thus, NL's data appear to be as reliable as those of the controls.

It is also notable that NL's overall reaction times improved over the course of the task. Reaction times for 0° items in the initial 50% of trials was some 1900 ms, while this was reduced to approximately 1500 ms in the second 50% of trials (i.e. almost within the range of the control subjects). However, this improvement in performance, which makes it less plausible to argue that NL is adopting an 'unusual' cognitive strategy to perform the task, was not associated with an increase in extent to which the data showed the linear increase in reaction time seen in control subjects. Thus, NL showed a higher slope value (–0.07) for the first 50% of data (i.e. those with slower overall reaction times), and for the second 50% of data (–0.39; i.e. those with faster overall reaction times).

In addition, a spilt-half analysis was performed on the slowest 50% versus the fastest 50% of NL's latency data[1]. The data for the 'faster' reaction times (which had a severely truncated range) were low for both NL and the controls, although notably no control performed as poorly as NL on both measures. NL's slope was 0.20, with an r^2 value of 0.01. The slopes for the controls were –0.06, 0.10, 0.20 and 0.32, with r^2 values of 0.10, 0.26, 0.61 and 0.87. The data were more revealing for the 'slower' reaction time data. Here, NL's slope was again low, at 0.02, with an r^2 value of 0.12. However, the slopes for the controls were much higher at 0.25, 0.59, 0.78, and 0.84, with r^2 values of 0.25, 0.35, 0.61 and 0.76. Thus, while these effects are modest, probably as a result of the truncated range, it is clear that NL showed no reliable effect of orientation. In contrast, the controls showed moderate effects in the 'slower' reaction time condition where the data were not overly truncated.

Comment. Consistent with previous claims (Turnbull *et al.*, 1997a), these data suggest that NL can accurately name objects. However, as predicted, the nature of NL's latency performance differed substantially from that of the controls.

First, it is of some note that NL's overall latency performance was slower than those of the controls. However, it is perhaps not surprising to see that the reaction times for a neurological patient (who in this case has suffered a substantial cerebrovascular accident; see especially NL's computed tomography scan; Turnbull *et al.*, 1997a) are slower than the reaction times of control subjects, given that speed of response is regularly compromised after brain injury, almost regardless of lesion site. Indeed NL showed faster naming reaction times than the one other patient we have reported who has performed this task (Turnbull and McCarthy, 1996a). We consider that the issue of the overall latency of NL's naming performance is not the most important feature of these data.

More importantly, NL's performance was significantly different from the control subjects both in terms of the magnitude of the correlation and the slope of the function. Unlike the controls, NL showed no increase in reaction time as a function of orientation. Moreover, a split-half analysis of the data showed that the absence of a positive slope is consistent across the two halves of NL's data, while the presence of a positive slope is consistent across the data of all the control subjects. Thus, a likely interpretation appears to be that orientation was not a significant factor in NL's mechanism of object identification—which suggests that NL was not employing an analogue (or 'mental rotation') strategy.

Of course, it might also be argued that the absence of a positive slope in NL's case may be related to the fact that his overall reaction times were slower than those of the controls. However, in our previous case (and in sharp contrast to NL) the patient showed a substantial linear effect of orientation on reaction time (Turnbull and McCarthy, 1996). Thus, it appears that it is merely the slope of the reaction time function, rather than the overall latency finding, that is abnormal in NL. A further possibility might be that NL's data simply show greater variability than those of the controls, and hence that the absence of a positive slope (even when it is found in all of the controls) might be a chance result. However, the split-half analysis of the data of all of the subjects suggests that NL's performance shows no more variability than that of the control subjects.

A further point relates to the potential confounding effects of hemispatial neglect. It could be argued that NL's poor performance might be a result of his inability to perceive the entire object. This seems unlikely, for two reasons. First, NL's neglect is present only in the imagery, but not the perceptual, domain (Beschin *et al.*, 1997). Second, NL's naming ability is excellent (1/240 errors), and comparable with that of the controls. This is not consistent with the claim that he was able to attend to only part of the object.

One final explanation for NL's poor performance might be that he is uncertain, or uncomfortable, in his performance on reaction time tasks—where the presence of the experimenter and computer suggests some degree of time constraint. This is not apparent in the measures of the variability of his performances. Thus, it seemed appropriate to test NL on another reaction time task. We were aware, from our previous investigations of such subjects (Turnbull and McCarthy, 1996; Turnbull *et al.*, 1997a), that they are often able to discriminate accurately between mirror image objects, and that such discriminations form the basis for reliable tests of mental rotation ability. To investigate these issues further, NL performed a Shepard and Metzler (1971)-type 'mental rotation' task.

Task 2. Mental rotation

The processes employed in recognizing a rotated object are not necessarily the same as those involved in discriminating between rotated mirror image objects (cf. Farah and Hammond, 1988; McClosky *et al.*, 1995). To test NL's performance on such mirror image tasks, we employed the stimuli used by Shepard and Metzler (1971) in their classic mental rotation experiment—the task being to determine whether the two picture–plane rotated objects are rotated but otherwise identical or rotated and mirror images.

Stimuli. The figures were pairs of the group of forms used by Shepard and Metzler (1971). One form was chosen as the model, for comparison against a target presented in one of six different orientations: 0, 60, 120, 180, 240 and 300°. To clarify the experiment for NL, and the other elderly subjects, a simplified version of Shepard and Metzler's (1971) task was used [previously employed in Turnbull and McCarthy (1996b)], in which the model was always the 0° version of the form, with only the target varying in orientation. On half of the trials the forms were the same (albeit rotated), and on the remaining (different) trials one of the pair was the mirror image (albeit rotated) of the other. Each block consisted of 36 items.

Procedure. Testing was carried out using a Macintosh Powerbook 520c, using Superlab software. The stimuli were presented sequentially, in randomized order, in the centre of the screen, and remained there until the subject responded. To match this task as closely as possible to task 1, and to simplify the task for NL, this task also required only a verbal response. The 36-trial block was presented four times (i.e. 144 items), in the same test session, with a brief rest break between blocks. The same four control subjects as in task 1 were also tested.

Results. The control subjects made an average of 15.1% errors (standard deviation = 5.3%), while NL made 26/144 errors (18.1%). Again, all incorrect responses and outlying reaction times (greater than two standard deviations) were removed from the latency analyses. In the case of NL, this involved removing 5.6% of the reaction time data. For the controls, this involved removing between 3.3 and 5.6% of the reaction time data.

All of the subjects, including NL, showed a linear increase in response latency as a function of orientation, with r^2 values ranging between 0.48 and 0.92 (see Fig. 2). Using the

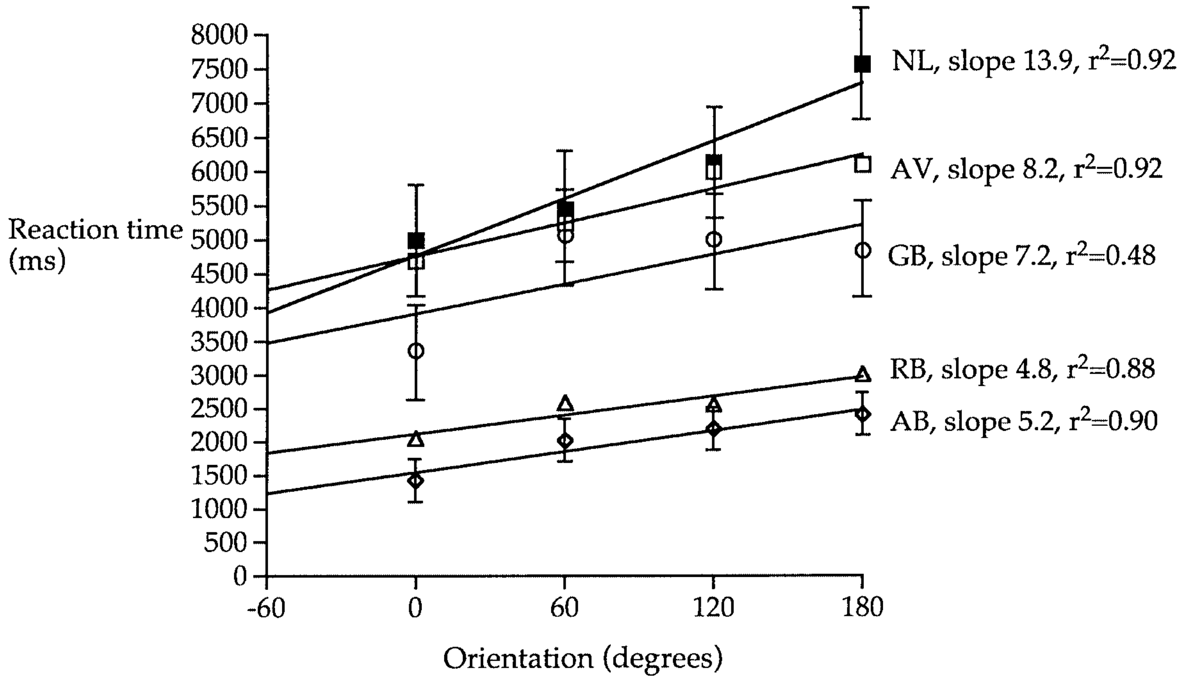

Fig. 2. Performance of NL and the control subjects on a mental rotation task. Data from 240 and 300° have been collapsed on to the 120 and 60° findings to simplify interpretation. Error bars represent one standard deviation, and are included for NL and the controls with the greatest (AB) and least (GB) variance.

modified independent samples *t*-test method described in task 1 (Crawford and Howell, 1998), NL's correlation was shown not to be significantly different from that of the controls ($t_{(3)} = 0.69$, $P > 0.05$). The slope of the function varied across the control subjects (varying between 4.75 and 8.24 ms/°) with NL's slope being steeper than the other controls at 13.9 ms/°, which was significantly different from that of the controls ($t_{(3)} = 4.12$, $P < 0.05$).

Comment. The results of the mental rotation task stand in sharp contrast to those of the earlier naming task. NL's latency performance increased (in a highly correlated manner) as a function of orientation. The slope of this function was significantly different from that of the controls, but (unlike the previous naming experiment) this was because the slope was steeper than that of the controls. That is, NL showed a greater effect of orientation on reaction time. This is consistent with the claim that NL is using a 'mental rotation' strategy to solve this task and suggests that NL's transformation strategy is not as rapid as that of the neurologically normal subjects. It is not clear why it might be that NL's rate of angular transformation is slowed. This question has not received prominence in the neuropsychological literature on mental rotation deficits, at least in part because so many of the earlier studies measured only accuracy, rather than speed, of performance (e.g. Kim *et al.*, 1984; Farah and Hammond, 1988).

These data are important with regard to the interpretation of the data from task 1. In discussing that experiment, it was shown that NL showed no effect of orientation on reaction time, but it was suggested that this might have been due to NL being uncertain or uncomfortable in performing reaction time tasks. However, the data from task 2 suggest that NL can perform such tasks with a high level of accuracy, and with a correlation that suggests that he can perform the task as reliably as controls. Most importantly, NL does appear to show an effect of orientation on reaction time on this task—indeed, an effect greater than that of the controls.

Task 3. Misoriented faces

There is another task in which there are dramatic effects of orientation on naming—that of recognizing misoriented faces. There is a substantial literature which suggests that normal subjects are far less accurate in naming faces which are presented upside down (Yin, 1969; Valentine and Bruce, 1986). If NL recognizes objects using a mechanism that is entirely independent of orientation, it might be expected that he would show no decrement in performance when recognizing inverted faces. However, it is also widely accepted that the mechanism by which common objects are recognized is not shared with that of faces. This question was investigated in NL using four separate face matching and face naming tasks.

Subjects. The control subjects were the same as those in tasks 1 and 2. However, data from an additional subject (62 years old and also matched for education) were also available, and were included.

Stimuli and procedure. For each test the stimuli were presented to the subject in the normal test sequence, but the

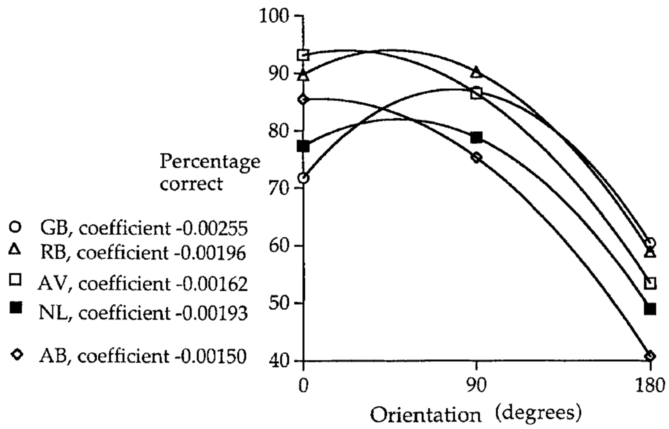

Fig. 3. Aggregate performance of NL and the control subjects on four face naming and matching tasks. The statistical analysis is based on the coefficient of the second-order term (i.e. the quadratic equivalent of the 'slope' for a linear function).

test materials were rotated continually through 90° after each trial. Thus, item 1 was at 0°, item 2 at 90°, item 3 at 180°, item 4 at 270°, then item 5 at 0°, etc. The various tasks have been reported elsewhere (Levin *et al.*, 1975; DeRenzi *et al.*, 1989, 1991; Della Sala *et al.*, 1995). The details of each task are as follows: (i) the famous faces recognition task consisted of 32 items (eight each at 0, 90 and 180°, and 12 at 270°); (ii) the famous faces multiple choice task consisted of 32 items (eight each at 0, 90 and 180°, and 12 at 270°); (iii) the Benton face matching task consisted of 54 items (14 each at 0, 90 and 180°, and 12 at 270°); (iv) the age judgement task consisted of 12 items (six at 0°, and three each at 90 and 180°).

Results. There were relatively few data points for each task, and it was thought that an analysis based on the data from each task might be less reliable than a measure which captured the data from 0, 90 and 180° on all tasks. Thus, the data presented below represent the aggregate performance for the four tasks. As in the earlier studies, data from the 90 and 270° performances have been collapsed to simplify interpretation. Performances of the control subjects, and NL, are shown in Fig. 3.

It is clear that NL showed a similar effect of orientation on accuracy to that of the control subjects. However, unlike tasks 1 and 2, the data do not conform to a linear trend, and are best described by a second-order polynomial ($y = ax^2 + bx + c$). The statistical analysis for these data is most appropriately based on the coefficient of the second-order term (i.e. a in the equation, which is the quadratic equivalent of the 'slope' for the linear functions in tasks 1 and 2). Using the modified independent samples t-test method described in task 1 (Crawford and Howell, 1998), the coefficient of NL's second-order term was shown not to be significantly different from that of the controls ($t_{(3)} = -0.043$, $P > 0.05$). In contrast to tasks 1 and 2, there is no advantage to attempting an analysis based on the r^2 values for the functions of the individual subjects, given that quadratic functions will always pass through all three points on any graph (hence generating r^2 values of 1.00).

Comment. The results of the misoriented faces task show that NL has a relatively 'normal' pattern of the recognition of misoriented faces. This finding is surprising, in the context of the many other tasks (i.e. in copying, matching and naming) on which NL appeared to show little, or no effect of orientation on accuracy and reaction time. However, as suggested above, there is substantial evidence that the recognition of faces employs mechanisms that are not always shared with those used to recognize common objects (Farah, 1990; Grusser and Landis, 1991).

Discussion

The previous report of NL's performance on tasks of naming and orientation (Turnbull *et al.*, 1997a) suggested clearly that he (like a number of similar patients: Solms *et al.*, 1988, 1998; Turnbull *et al.*, 1995, 1997a; Turnbull, 1996) is capable of naming objects. However, he appears to have limited access to orientation information for these same items. Thus, we have argued that NL has an 'orientation agnosia'. NL's lesion site involved the right inferior parietal lobule and he had other visuospatial deficits. Therefore, these data were taken as support for the claim that such patients represent instances of isolated access to the proposed (Kosslyn *et al.*, 1990, 1994; Biederman and Gerhardstein, 1993; Milner and Goodale, 1995) viewpoint-invariant object recognition systems of the ventral visual stream. In principle, the present study was designed to establish not only whether NL's object recognition abilities were still normal in terms of accuracy, but also in terms of their temporal properties. It was predicted that he would not show the characteristic slowing of reaction time seen in recognizing misoriented objects. In practice, the evidence from the tasks reported in the present study opens up a number of complex questions, and bears heavily on several issues in the broader object recognition literature.

First, we will discuss the evidence of NL's performance in the naming experiment (task 1). In contrast to the performance of all of the control subjects, NL showed no significant correlation between orientation and reaction time. NL's reaction time performance was not more variable in comparison with that of the control subjects, and showed a level of split-half reliability comparable with the control subjects. However, as noted above, his reaction time performances on task 2 were excellent, which suggests that NL had no particular difficulties in performing reaction time tasks. Thus, these data suggest that, unlike the control subjects, NL showed no reliable effect of orientation on naming reaction time. These findings should also be considered in the context of earlier data, which showed similar effects of an absence of orientation information on a wide range of different tasks. That is, NL (Turnbull *et al.*, 1997a; see also Solms *et al.*, 1988, 1998; Turnbull *et al.*, 1995; Turnbull, 1996) copies drawings by rotating them through 90 or 180°, fails to choose the correct orientation for single objects when offered the opportunity to view them in a range of orientations, and fails to choose a rotated object on an odd-one-out task. Together, these data suggest that NL recognizes misoriented objects using a mechanism which is independent of viewpoint (cf. Marr, 1982; Biederman, 1987), rather than employing an analogue transformation (i.e. 'mental rotation') solution to the problem.

However, it should also be clear that NL's performance in the 'mental rotation' experiment (task 2) appears to run contrary to this interpretation. He performed the mental rotation task with a high degree of accuracy, and showed the linear increase in reaction time as a function of orientation that is considered characteristic of mental rotation performance (Shepard and Metzler, 1971). How is it possible to argue that NL does not recognize misoriented objects using the characteristic 'mental rotation' strategy of control subjects, and simultaneously that he performs normally on a task of mental rotation?

A likely answer is that the task of classic mental rotation (where an object must be discriminated from its mirror image; Shepard and Metzler, 1971) has a different neural basis from the transformational strategy employed for the purposes of object recognition (a task where mirror image discrimination is almost always irrelevant; cf. McClosky *et al.*, 1995). This issue is clarified by reports of a double dissociation in this domain. There have been several patients (Farah and Hammond, 1988; Morton and Norris, 1995) who performed very poorly on tasks of mental rotation, while having a preserved ability to recognize picture–plane misoriented drawings of objects. In contrast, a patient who performed poorly when recognizing misoriented objects, but retained good performance on tasks of mental rotation, has also been reported (Turnbull and McCarthy, 1996b). Thus, while the mirror image and naming tasks both appear to involve mental rotation-like image transformation, these data suggest that they do not share a common cognitive architecture. Indeed, it has been suggested that the 'mental rotation' effect seen in object recognition may result from a physiological process (accumulation from cell populations) which may not represent an example of 'analogue' image manipulation (Perrett, 1996; Perrett *et al.*, 1998).

A further, anatomical, issue bears on the question of the dissociation seen between NL's performance on common object items (task 1) versus face items (task 3). While there are methodological differences in the way these tasks were designed, they may bear on the question of hemispheric specialization. As discussed above, there is clear evidence for a system specialized for mental rotation, probably in the right parietal (i.e. dorsal stream) region. Object recognition systems are ventrally located and show hemispheric asymmetry, with a right bias for faces and places and a left bias for common objects. On this account[2], NL's pattern of performance might be interpreted as resulting from a left hemisphere 'common object' recognition system (ventral) which is disconnected from the right hemisphere (dorsal) mental rotation system by virtue of his parietal lesion. In contrast, the right hemisphere 'face' recognition system (ventral) would retain access to the right hemisphere (dorsal) mental rotation system, explaining NL's preserved performance on face recognition tasks.

The findings of the present study therefore seem to strengthen the argument that the dramatic errors of orientation seen in patients such as NL result from an 'orientation agnosia', and support the claim that objects are typically recognized using a mechanism that is independent of viewpoint (Marr, 1982; Biederman, 1987). The anatomical and clinical data from NL (which suggest that his lesion site has left the ventral visual system more or less intact) also suggest that it is the ventral visual system, the primary route to object recognition, which employs such a viewpoint-independent mechanism. However, some recent single-neuron findings in the macaque monkey (Rollenhagen and Olsen, 2000; Olsen, 2001) suggest that the ventral visual system does have a capacity to differentiate between objects based on their orientation. However, the extent of this ability depends, for example, on whether the image is a vertical or horizontal transformation. It is clear that closer investigation of this issue is required in order to address the key question of whether our knowledge of objects is stored in an orientation-invariant way.

In addition, Karnath *et al.* (2000) have suggested that patients such as NL (Turnbull *et al.*, 1995, 1997; Turnbull, 1996; Solms *et al.*, 1998) do not have an orientation agnosia, because they make errors less frequently for items that are correctly oriented (i.e. at 0°). On this basis they have attacked the claim that such findings can be interpreted as suggesting that object structure is coded in an orientation-invariant way. Rather, they suggest, these findings offer support for Perrett *et al.*'s (1998) argument that neurons involved in object recognition are 'tuned' to view particular orientation, based on experience (Karnath *et al.*, 2000, p. 1240). The results of the present study offer mixed support for Karnath *et al.*'s claim—for example, the fact that 0° items are recognized no faster than rotated items. This interpretation is also not consistent with a recent investigation from our group (Caterini *et al.*, 2002) in patients with Alzheimer's disease. Here, each of the three key patients in our 'dissociation' series (i.e. patients who show NL-like performance) showed errors for 0° items, in contrast to Karnath *et al.*'s patient. Indeed, our patients made as many errors at 0° as they did at 120°, which might argue against Karnath *et al.*'s 'tuning' claim.

Acknowledgements

The authors wish to thank Professor John Crawford for his advice and assistance with the statistical analyses. The Crawford and Howell statistical test (Crawford and Howell, 1998) can be downloaded at: http://www.psyc.abdn.ac.uk/homedir/jcrawford/psychom.htm.

This work was supported by grants to OHT from the Nuffield Foundation (SCI/180/95/614/G) and the British Council (ROM/889/97/31).

Notes

[1]We thank an anonymous reviewer for this suggestion.
[2]We thank an anonymous reviewer for this suggestion.

References

Beschin N, Cocchini G, Della Sala S, Logie R. What the eyes perceive, the brain ignores: A case of pure unilateral representational neglect. Cortex 1997; 33: 3–26.

Biederman I. Recognition-by-components: A theory of human image understanding. Psychological Review 1987; 94: 115–47.

Biederman I, Gerhardstein PC. Recognising depth-rotated objects: Evidence and conditions for three-dimensional viewpoint invariance. Journal of Experimental Psychology 1993; 19: 1162–82.

Caterini F, Della Sala S, Spinnler H, Stangalino C, Turnbull O. Object recognition and object orientation in Alzheimer's disease. Neuropsychology 2002; 16: 146–55.

Crawford JR, Howell DC. Comparing an individual's test score against norms derived from small samples. The Clinical Neuropsychologist 1998; 12: 482–6.

De Renzi E, Bonacini MG, Faglioni P. Right posterior brain damaged patients are poor at assessing the age of a face. Neuropsychologia 1989; 27: 839–48.

De Renzi E, Faglioni P, Grossi D, Nichelli P. Apperceptive and associative forms of prosopagnosia. Cortex 1991; 27: 213–21.

Della Sala S, Muggia S, Spinnler H, Zuffi M. Cognitive modelling of face processing: evidence from Alzheimer patients. Neuropsychologia 1995; 33: 675–87.

Farah MJ. Visual agnosia: disorders of object recognition and what they tell us about normal perception. Cambridge: MIT Press, 1990.

Farah MJ, Hammond KM. Mental rotation and orientation-invariant object recognition: Dissociable processes. Cognition 1988; 29: 29–46.

Grusser O-J, Landis T. Visual agnosias and other disturbances of visual perception and cognition. London: Macmillan Press, 1991.

Jolicoeur P. Time to name disoriented natural objects. Memory and Cognition 1985; 13: 289–303.

Jolicoeur P. Identification of disoriented objects: a dual systems theory. Mind and Language 1990; 5: 387–410.

Karnath H, Ferber S, Bulthoff H. Neuronal representation of object orientation. Neuropsychologia 2000; 38: 1235–41.

Kim Y, Morrow L, Passafiume D, Boller F. Visuoperceptual and visuomotor abilities and locus of lesion. Neuropsychologia 1984; 22: 177–85.

Kosslyn SM, Flynn RA, Amsterdam JB, Wang G. Components of high-level vision: A cognitive neuroscience analysis and accounts of neurological syndromes. Cognition 1990; 34: 203–77.

Kosslyn SM, Alpert NM, Thompson WL, Chabris CF, Rauch SL, Anderson AK. Identifying objects seen from different viewpoints: A PET investigation. Brain 1994; 117: 1055–71.

Lambon-Ralph MA, Jarvis C, Ellis AW. Life in a mirrored world: Report of a case showing mirror reversal in reading and writing and for non-verbal materials. Neurocase 1997; 3: 249–58.

Levin HS, Hamsher KDS, Benton A. A short form of the test of face recognition for clinical use. Journal of Psychology 1975; 91: 223–8.

Logothetis NK, Sheinberg DL. Visual object recognition. Annual Review of Neuroscience 1996; 19: 577–621.

Marr D. Vision. San Francisco: WH Freeman & Co., 1982.

McClosky M, Rapp B, Yantis S, Rubin G *et al.* A developmental deficit in localising objects from vision. Psychological Science 1995; 6: 112–6.

Milner AD, Goodale MA. The visual brain in action. Oxford: Oxford University Press, 1995.

Morton N, Morris RG. Image transformation dissociated from visuopatial working memory. Cognitive Neuropsychology 1995; 12: 767–91.

Olsen CR. Object-based vision and attention in primates. Current Opinion in Neurobiology 2001; 11: 171–9.

Perrett DI. Recognition using cells in temporal cortex: Generating sensitivity to pattern configuration and explaining generalization over view without invoking mental rotation. Journal of Psychophysiology 1996; 10: 83.

Perrett DI, Oram MW, Wachsmuth E. Evidence accumulation in cell populations responsive to faces: an account of generalisation of recognition without mental transformations. Cognition 1998; 67: 111–45.

Pinker S. Visual cognition: an introduction. Cognition 1984; 18: 1–63.

Riddoch MJ, Humphreys GW. Description of a left–right coding deficit in a case of constructional apraxia. Cognitive Neuropsychology 1988; 5: 289–315.

Rollenhagen JE, Olsen CR. Mirror-image confusion in single neurons of the macaque inferotemporal cortex. Science 2000; 287: 1506–8.

Shepard RN, Metzler J. Mental rotation of three-dimensional objects. Science 1971; 171: 701–3.

Snodgrass JG, Vanderwart M. A standardised set of 260 pictures: Norms for name agreement, familiarity and visual complexity. Journal of Experimental Psychology: Human Learning and Memory 1980; 6: 174–215.

Sokal RR, Rohlf JF. Biometry, 2nd edn. San Francisco: WH Freeman & Co., 1981.

Solms M, Kaplan-Solms K, Saling M, Miller P. Inverted vision after frontal lobe disease. Cortex 1988; 24: 499–509.

Solms M, Turnbull OH, Kaplan-Solms K, Miller P. Rotated drawing: The range of performance, and anatomical correlates, in a series of 16 patients. Brain and Cognition 1998; 38: 358–68.

Tarr MJ, Pinker S. Mental rotation and orientation-dependence on shape recognition. Cognitive Psychology 1989; 21: 233–82.

Turnbull OH. Rotated drawing and object recognition. Brain and Cognition 1996; 32: 120–4.

Turnbull OH, McCarthy RA. Failure to discriminate between mirror-image objects: A case of viewpoint-independent object recognition? Neurocase 1996a; 2: 63–72.

Turnbull OH, McCarthy RA. When is a view unusual? A single case study of orientation-dependent visual agnosia. Brain Research Bulletin 1996b; 40: 497–503.

Turnbull OH, Laws KR, McCarthy RA. Object recognition without knowledge of object orientation. Cortex 1995; 31: 387–95.

Turnbull OH, Beschin N, Della Sala S. Agnosia for object orientation: Implications for theories of object recognition. Neuropsychologia 1997a; 35: 153–63.

Turnbull OH, Carey DP, McCarthy RA. The neuropsychology of object constancy. Journal of the International Neuropsychological Society 1997b; 3: 288–98.

Turnbull OH, Della Sala S, Beschin N. Rotated drawing: An MMSE performance with strong lateralising significance. Journal of Neurology, Neurosurgery and Psychiatry 1997c; 62: 419–20.

Ungerleider LG, Mishkin M. Two cortical visual systems. In: Ingle DJ, Goodale MA, Mansfield RJW, editors. Analysis of visual behavior. Cambridge, MA: MIT Press, 1982: 549–86.

Valentine T, Bruce V. The effect of race, inversion, and encoding activity upon face recognition. Acta Psychologica 1986; 61: 259–73.

Warrington EK, Taylor AM. The contribution of the right parietal lobe to object recognition. Cortex 1973; 9: 152–64.

Yin RK. Looking at upside-down faces. Journal of Experimental Psychology 1969; 81: 141–5.

Received on 10 May, 2001; resubmitted on 4 March, 2002; accepted on 13 March, 2002

Agnosia for object orientation: naming and mental rotation evidence

O. H. Turnbull, S. Della Sala and **N. Beschin**

Abstract

We have previously reported the performance of a patient (NL) who could recognize objects but appeared to lack knowledge of their orientation. These results were interpreted as evidence that NL had isolated access to a viewpoint-independent (ventral stream) object recognition system. However, because NL's responses on naming tasks were not timed, it was not possible to establish whether he showed the same pattern of reaction time performance generally accepted as evidence of a 'mental rotation' strategy in neurologically normal subjects. Here we report NL's performance on two reaction time tasks, testing his ability to transform images when naming, and discriminating between rotated mirror image objects. As predicted, and in contrast to normal volunteers, NL showed no 'mental rotation' effect in his naming of misoriented objects. Paradoxically, he performed well on a traditional Shepard and Metzler mental rotation task. He also showed a normal orientation effect when dealing with misoriented faces. These findings offer further support for viewpoint-independent theories of object recognition, and bolster the claim that object orientation knowledge can be regarded as, in some respects, a special class of spatial information.

Journal

Neurocase 2002; 8: 296–305

Neurocase Reference Number:

O262

Primary diagnosis of interest

Middle cerebral artery infarction

Author's designation of case

NL

Key theoretical issue

- Bolsters the claim that object orientation knowledge can be regarded as, in some respects, a special class of spatial information

Key words: object recognition; orientation; misoriented; spatial; mental rotation

Scan, EEG and related measures

Computed tomography

Standardized assessment

Mini Mental State Examination (MMSE), tests of abstract reasoning, calculation, long-term verbal memory, neglect in perception and imagery, visual short-term memory, constructional praxis, object recognition

Other assessment

Three custom-designed tasks: a reaction time measure of naming, a reaction time measure of mental rotation and an untimed measure of face recognition and matching

Lesion location

- Right middle cerebral artery territory

Lesion type

Stroke/infarction

Language

English