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WALKING TRAJECTORY AND HAND MOVEMENTS IN UNILATERAL LEFT NEGLECT: A VESTIBULAR HYPOTHESIS

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Abstract—This is the first systematic study of walking trajectories in unilateral neglect. Six patients with unilateral left neglect approached and walked through a doorway, and all six deviated to the right of centre when doing so. Four out of six significantly centred their walking trajectories by making left hand movements while approaching the doorway. The group effect of walking with no hand movements vs walking with hand movements was statistically significant. Age-matched control patients showed a similar but significant smaller rightward deviation. The results are interpreted in terms of recent research in limb activation effects on neglect (Robertson and North, *Neuropsychologia* **30,** 553–563, 1992), and also in the light of research showing close anatomical correspondence between the cortical projections of the vestibular nerve on the one hand, and the hand/arm representational fields of the central sulcus on the other.

Key Words: neglect; inattention; vestibular; walking; rehabilitation; attention.

INTRODUCTION

Unilateral visual neglect is a major feature of damage to the right hemisphere and typically produces inattention for objects and people located on the left (or contralesional) side of space [3, 6, 10, 16] and "leftness" can be defined according to retinopic object-centred, saggital mid-line and other frames of reference [9, 22]. A distinction between "output" (intentional) and "input" (attentional) neglect has also been made [27] and dissociations between neglect of personal space and peripersonal space [7] and between peripersonal space and extrapersonal space [8] have also been described.

An often-mentioned feature of unilateral left neglect is the tendency of patients to veer to the right while following familiar routes [3], a phenomenon which has also been demonstrated when mentally tracing familiar routes [1]. On the other hand, another commonly-reported problem in unilateral neglect is the tendency to make left-sided collisions with doorposts, furniture, etc. [12, 32].

Studies of blindfolded normal subjects show that approximately two-thirds rotate to the right in walking and stepping tasks [13, 17, 26, 34], and this has been explained in terms of cerebral lateralisation related to the vestibular system [17]. Previc suggests that cerebral lateralisation in human derives from the asymmetric prenatal development of the ear and vestibular system, and that the greater sensitivity of the left otolith, results in a body tilt to the opposite, right side. Previc attributes the rightward rotation of the majority of normals to this rightward tilt.

The fact that such gross deviations in normal human walking are not observed where subjects are not blindfolded suggests that visual attention compensates for this vestibular imbalance. Given that visual attention to the left is impaired in unilateral neglect, one could predict that the rightward vestibular bias would have a stronger effect where visual attention to relatively leftward visual reference points is depressed. To give a specific example, one would predict that in walking through a doorway, the person may fail to attend to the left doorpost, and hence the walking trajectory would be relatively more influenced by attention to the right doorpost.

Yet this prediction does not at first glance accord with clinical observations of collisions on the left which are commonly observed [12, 32]. This is however less contradictory than it first seems when one considers where attention is deployed in regulating a given walking trajectory. If a patient is for instance walking down a corridor, then she may use the far doorway as a reference frame to guide her trajectory and may begin to veer to the right as a result of the relative inattention for the left doorpost. However in the course of walking, she may fail to observe intermediate obstacles, and it is likely that she would more readily fail to notice obstacles on the left than on the right, and hence would be more likely to collide with them. In other words, a relatively simple model of visual attention bias to the right combined with a vestibular bias to the right predicts that both right and left collisions would take place, depending on the number of obstacles, and on the location of these obstacles between the person and middle-distance "navigational" focus of attention.

Another simple reason why left collisions may predominate in clinical reports is that left hemiplegic patients in wheelchairs push the right wheel with the right hand, which automatically causes the wheelchair to veer slightly to the left. In addition, one might predict that a neglect of the left side of the body—i.e. "personal neglect" [7, 18, 20, 21] might result in collisions with objects on the left side. However, as mentioned above, both left- and right-sided collisions can be predicted for a simple model based on inattention for left-sided spatial reference cues combined with a vestibular "push" to the right side.

This proposed role of the vestibular system in neglect is further strengthened by research showing significant improvements in many aspects of neglect, spatial functioning, hemianaesthesia and other associated problems following vestibular (caloric) stimulation [4, 28, 29, 31]. Hence there are grounds for predicting that neglect patients may show an exaggeration of the normal tendency to deviate to the right, even when they are not blindfolded, given that the undamaged left hemisphere—including its vestibular system—is relatively uninhibited by the damaged right hemisphere [11].

A further question arises in the context of research showing that contralesional limb activation can significantly reduce perceptual aspects of neglect [23–25]. If there is a consistent tendency to veer to one side during locomotion, is this influenced by limb activation of the type which has produced effects on reading and cancellation tests? If so, then this would produce strong replication of the limb activation phenomenon using a completely different paradigm.

In this study, patients were required to walk through a doorway with and without hand movements. There were two questions posed in this study: would patients veer to the right as predicted by studies of blindfolded normals? Secondly, if they do, would this be ameliorated by concurrent hand movement as predicted by previous work on hand movements in neglect?

METHOD

Procedure

Subjects were positioned in front of a 100-cm-wide doorway,* 4 m in front of it, and with their body midlines in line with the mid-point of the doorway. They were instructed to walk through the doorway normally, but no further instructions were given. At the point they reached the doorway, they were stopped and the position of the top of their head measured with respect to a scale in centimetres placed across the top of the doorway, and visible to the experimenter but not the subject. This was repeated 10 times for each subject, and the mean percentage deviation from centre was calculated for each subject, deviations to the right of centre being positive, and those to the left being negative.

In half of these trials for each subject, in addition to being given the same instructions to walk through the doorway, subjects were asked to clench and unclench their left hand approximately once per second while walking. The hand move and no hand move trials were randomly interspersed.

Subjects

Six subjects suffering from unilateral neglect were tested, along with six age- and sex-matched controls recruited from the MRC Applied Psychology Unit Subject Panel. The experimental procedure was identical for both groups. Table 1 summarises the subject data.

RESULTS

Table 2 shows the mean deviations from true centre of the doorway for all 12 subjects, as well as a mean % deviation for the patient and control groups respectively, for both the normal walking condition and the hand move condition.

Analysis of variance shows both a significant group effect (controls vs patients: $F=10.98$; $P=0.003$) and a significant effect of condition (no hand move vs move: $F=5.46$; $P=0.03$), as well as a significant group by condition interaction ($F=5.17$; $P=0.03$). *Post-hoc* t-tests show that walking deviation during the neglect no move condition was significantly greater than every other condition (vs control no move: $t=-4.5$; $P=0.006$; vs control move: $t=-4.0$; $P=0.001$; vs neglect move: $t=3.1$; $P=0.03$). The neglect hand move condition did not however differ significantly from either of the control conditions.

As is clear in Table 1, all neglect subjects deviate to the right of centre in this task during normal walking, with a mean deviation of approximately 15% of the doorway width. There is a variation ranging from 8.4% in subject 2—22.9% in subject 3. Subject 1 has a particularly high standard deviation compared to the other subjects. Control subjects all also deviate to the right of centre, but by a smaller amount, the mean being 3.4% (this deviation is significantly different from zero: $t=4.66$; $P=0.005$). The highest control deviation is lower than the lowest neglect deviation.

Table 1 also shows the results for the hand move condition, again for each subject as well as for the two groups as a whole. Statistically significant differences were found between the normal and hand move conditions for neglect subjects 1, 4, 5 and 6, but not for subjects 2 and 3. Control subject 5 showed a significantly smaller deviation under the hand move condition compared to the no hand move, while all other control subjects failed to show both significant effects or consistent trends for hand move.

*In one of the six cases—subject 2—for practical reasons a doorway of 137 cm was used. Data on this case have been converted to percentages, such that the mean deviation scores for all six subjects are directly comparable.

Table 1. Summary of patient characteristics

Subject	Age	Weeks post	CT scan–lesion location	Clinical features	Neglect assessment
1	63	12	Right front haemorrhage, with some low attenuation of white matter in frontal lobes bilaterally	Left homonymous hemianopia; mild weakness in left arm and leg	Behavioural Inattention Test [33]: 4/9 on representational drawing, 4/9 drawing from memory, 2/9 on picture scanning, 1/9 on telephone dialling, 0/9 on article reading, 7/9 on reading and setting the time, and 1/9 on map reading
2	41	8	Right frontal contusions and haematoma excised following closed head injury	Reduced power in left shoulder and leg, reduced coordination in left arm	Behavioural Inattention Test: 5/9 on line bisection, 3/4 on figure copying and 48/54 on star cancellation
3	65	16	Old infarcts deep in right hemisphere and in right frontal lobe; recent infarction in right occipital lobe	Left homonymous hemianopia; left hemiparesis resolved by time of testing	Had shown severe left neglect in the three months post-stroke, but at 4 months post-stroke, had undergone scanning training and was able to compensate on most formal tests of neglect. On line bisection, however, his mean deviation to the right of centre on 10 trials of 180 mm line bisection was 67 mm (S.D. 9.7)
3	74	2	Right temporal–parietal–occipital infarction	Left homonymous hemianopia; normal power and sensation	Scored 7 out of 40 lines on Albert's Test. Copied objects only on the extreme right and only drew digits on the right side of a clock face
5	64	20	Right tempero-parietal haemorrhage	Left homonymous hemianopia; normal power and sensation	On line bisection bisected a 180 mm line 52 mm to the right of the true midpoint, and marked only 4 lines out of 40 on the extreme right of Albert's test
6	66	2	*CT scan taken too early to show any infarct*	Normal visual fields, normal power and strength	Six lines on the extreme left of Albert's Test at 7 days post-stroke; marked left-sided omissions on a drawing task at 2 weeks post-stroke

Table 2. Mean deviation in doorway task for six patients and six controls in no move and hand move conditions, respectively

Subject	Patient normal walking mean % deviation (S.D.)	Patient walking while clenching hand	Control walking mean (S.D.)	Control walking with hand moves
1	+19.0 (11.9)	1.5 (13.9)[1]	+5.9 (1.8)	+6.3 (1.8)[n.s.]
2	+8.4 (3.9)	9.4 (3.8)[n.s.]	+0.9 (1.5)	+1.7 (1.9)[n.s.]
3	+22.9 (3.0)	21.4 (3.0)[n.s.]	+2.1 (2.2)	+1.8 (1.4)[n.s.]
4	+18.6 (3.1)	2.2 (3.7)[2]	+2.7 (4.6)	+4.6 (3.7)[n.s.]
5	+10.9 (2.0)	0.4 (1.6)[3]	+4.4 (2.8)	+0.6 (3.8)[5]
6	+13.4 (2.2)	−1.4 (3.0)[4]	+4.3 (0.9)	+4.6 (1.6)[n.s.]
Whole group	**15.5 (5.4)**	**+5.4 (8.5)**	**+3.4 (1.8)**	**+3.3 (2.2)**[6]

Differences between move and no move conditions for each patient (n.s. = non-significant): [1] $t=3.85$; $P<0.004$; [2] $t=16.5$; $P<0.0001$; [3] $t=10.71$; $P<0.0001$; [4] $t=15.18$; $P<0.001$.

Differences between move and no move conditions for control (n.s. = non-significant): [5] $t=2.6$; $P<0.03$; [6] see text for ANOVA results.

DISCUSSION

Direction of deviation in no move condition

The experimental paradigm used revealed a consistent right-of-centre deviation for both neglect and control subjects, with a much stronger effect for the former. None of the neglect subjects showing any tendency towards leftward deviation of the kind which would be likely to cause collisions with obstacles on their left sides, which is what was predicted in the introduction above to be the case in an otherwise uncluttered walking path.

One hypothesis to explain the observed results is that the attention of subjects is "captured" by the right doorpost, and that this attentional capture combined with a vestibular bias to the right leads has been observed in veering behaviour. Such an automatic "early attraction" to the right has been demonstrated in neglect subjects [5]. The fact that the normal subjects all deviated slightly to the right during walking tends to support such a hypothesis, namely that the rightward veering of the neglect patients may be exaggerated form of a normal response related to vestibular dominance as outlined by Previc [17]. Other explanations are also possible, for instance a "mutilated repesentation" of the left side of space resulting in a tendency to behave as if that side of space did not exist [2, 19]; by this argument, the ipsilesional doorpost would be the only navigational feature, with the result that the subject would of course veer towards it, in the absence of any other feature on the right of which he or she was aware.

Effects of hand movements on walking trajectory

Robertson and North [23–25] showed that requiring a neglect patient to make a series of purposeful movements with his partially hemiparetic left hand during performance of cancellation tasks led to a significant reduction in neglect on cancellation and reading tasks. This was true even when he could not see his left arm or hand, but it was *not* true when he moved his left hand in right hemispace, nor when he moved his right hand in left hemispace. The hypothesis advanced to explain these findings drew on Rizzolatti and Berti's [18] theory of spatial representation. This proposes that personal space, reaching space and locomotor space are each controlled by independent but co-ordinated neuronal circuits. Left limb activation in left hemispace results in activation of the left sides of both reaching and personal space. The resulting synchronous activation of two circuits produces a lowering of threshold for attention to the left side which is not achievable by activation of either the left hand in space alone nor by the activation of the right hand in left space alone.

The present study partially replicates these previous findings [23–25] using a quite different paradigm, namely walking through a doorway. In spite of the overall significant group effect, however, the effect was only apparent for four of the six neglect subjects, and subjects 2 and 3 showed no effect of hand clenching. Scrutiny of Table 1 suggests no systematic difference between these two subjects and the other four in terms of location of lesion—although both showed frontal damage; this was also the case for subject 1, who did show the hand move effect very strongly. The fact that one of the control subjects showed a hand move effect may be a chance finding and further research is in progress to see whether this is indeed the case. The fact that there was no clear trend in that direction for the control subjects argues against the possibility of some small but finite generalised effects of left hand movements on normal locomotion, although this argument is weakened by the fact that there is no unilateral hypoactivation in the normal group.

One possible explanation for the neglect hand move effects rests upon the fact that there is a representation of the vestibular system in the neighbourhood of the hand area in sensory strip of the cortex. Ödkvist and colleagues [15] found that in the squirrel monkey, there was a vestibular inflow to the anterior bank of the central sulcus. The zone in question was a small one and located within the arm field. Surface positive potentials and negative field potentials were evoked in this field by isolated stimulation of the vestibular nerve. It was localised as area 3A, from the fundus of the central sulcus onto the cortical surface anterior to this sulcus. Ödkvist *et al.* found a vestibular projection in area 3A in the cat [14]. They found that the post cruciate vestibular field, located in area 3A, has a high degree of convergence between vestibular and peripheral somatosensory input, the latter not restricted to muscle afferents, but including cutaneous modalities. Grusser *et al.* [6b] have more recently confirmed the considerable convergence of upper limb and vestibular inputs to the cortex in Java monkeys, as well as providing a comprehensive bibliography on this phenomenon.

These data raise the possibility that the limb activation effects demonstrated in the present study and its predecessors *may* operate via a similar mechanism to that involved in vestibular stimulation (one caveat here is that *left leg* activation has also been found to reduce left visual neglect [24], suggesting that the effects are not limited to area 3A and the arm field). Vallar and his colleagues [28–31] have sought to explain the dramatic effects of vestibular stimulation on neglect and a wide range of other disorders in terms of its restoring a correspondence between somatotopic sensation on the one hand and egocentric representation on the other. One might argue that left hand movements may have a similar effect through activating the vestibular system in area 3A, though one would then have to explain why left arm movements only have such an effect in left hemispace and not made in right hemispace [23], as well as why left leg movements have produced reductions in neglect [24].

Unfortunately, there was no left hand move in right hemispace condition in the present experiment, and so the more parsimonious explanation for the present data remains an activation of the vestibular system through activation of the neighbouring hand area of the sensory strip. Further experiments will rest whether left hand moves in right hemispace produce a similar effect. The vestibular hypothesis would predict that they should. If they do not, then one would require a more complex theoretical explanation of the effect observed in the present study along the lines proposed in the previously-mentioned series of limb-activation studies [23–25].

Perhaps the more parsimonious explanation of all is that the left hand movements produce a general, non-specific, activation of a hypoactive right hemisphere, which is related neither to the vestibular representation in the cortex nor to more complex interactions between different spatial systems. The present data cannot exclude such a hypothesis, though the left-hand-move-in-right-hemispace condition needed to distinguish between the vestibular and the interacting-spatial-circuits hypotheses would also allow this third non-specific activation hypothesis to be tested. We are currently running this experiment using all the left vs right hand moves in left vs right hemispace permutations used in the original limb activation studies.

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