Exploration of social rule violation in patients with focal prefrontal neurosurgical lesions

R G Morris[1], E Pullen[2], S Kerr[3], P R Bullock[4] and R P Selway[5]

[1]Neuropsychology Unit, Department of Psychology, [2]Department of Psychology,
Institute of Psychiatry, De Crespigny Park, London, UK

[3] VIRART, Human Factors Research Group, Innovative Technology Research Centre,
School M3, University of Nottingham, University Park, Nottingham, UK

[4,5]Department of Neurosurgery, Department of Neurosurgery,
King's College Hospital, Denmark Hill, London, UK

[1]*spjtrgm@iop.kcl.ac.uk,* [2]*Emily.Pullen@uclh.nhs.uk,* [3]*Steven.Kerr@nottingham.ac.uk,*
[4]*Peter.Bullock@kingsch.nhs.uk,* [5]*Richard.Selway@kingsch.nhs.uk*

[1]*www.iop.kcl.ac.uk*

ABSTRACT

Social rule violation was explored in 22 patients with prefrontal neurosurgical lesions and 22 normal controls. The patients were split into those with neurosurgical lesions impinging on the either the orbitofrontal (OF), dorsolateral (DL) or mesial (M) region of the prefrontal cortex. The study used a virtual reality 'bar' in which participants walked from the entrance to the bar counter, ordered drinks and returned to the entrance, with the choice of moving between other people (socially inappropriate) or around the people (social appropriate). There was a significant increase in socially inappropriate behaviour in the patients whose lesions were in other prefrontal regions than the dorsolateral prefrontal cortex.

1. INTRODUCTION

The ability to follow the social conventions or rules within a society is essential to human social interaction. These rules are learned at an early age through modelling, verbal instruction and reinforcement contingencies. Implicit rules are adhered to in many social settings and when these are violated, this leads to participants feeling uncomfortable and anxious. One particular social convention is to observe the rules concerning personal space and this has been explored using virtual reality. Specifically, Parsons, Mitchell and Leonard (2004) tested the ability of participants to observe social space in a virtual reality bar in which they had to avoid walking between to avatars that were closely facing each other, by taking a longer route to reach the bar. It was found that people with autistic spectrum disorder (ASD) were much more likely walk inappropriately between people than matched controls.

Although a relatively simple measure of social rule violation, this procedure shows that it is sensitive to differences in ASD. It is of interest to establish whether this type of Virtual Reality procedure could also detect social rule violations in other clinical disorders, and in particular those with brain damage. To test, this we studied a group of patients who had undergone focal prefrontal cortical neurosurgery. As well as impairments in the control processes associated with cognition and behaviour (executive functioning) such patients are known to display deficits in the ability to adhere to social conventions and understand social rules, despite in certain cases having previous knowledge of such rules and having experienced normal development (Saver and Damasio, 1991). The prefrontal cortex can be split into heterogenous functional regions, and it has been shown that there are specific associations between the orbitofrontal and mesiofrontal cortex concerning social or emotional function. This includes the demonstration that the damage associated with these regions affects the perception of emotion, the ability learn rapidly changes in social reinforcement, application of rule based behaviour, the modulation of emotional reactions and decision making within a social context (Barrash et al. 2000; Hornak et al. 2005; Morris et al. 2004). Hence, in this study we took patients with focal prefrontal cortical lesions and explored the location of the lesions in relation to putative impairments in the ability to observe social space. It was predicted that orbitofrontal or mesiofrontal rather than dorsolateral lesions would result in such impairment.

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(a) Conversation Blocking / Standing

(b) Conversational Blocking/ Sitting

(c) Social Proximity/ Shopping

(d) Social Proximity/ Standing

Figure 1. *(a) −(d). Starting views of the 4 trials used in the Virtual Reality Task.*

Social impairments in such patients tend to be more subtle than in ASD, so it was necessary to modify the existing Virtual Reality procedure in order to make it more sensitive. This was done by adding in subsidiary tasks to distract the participants from the main requirements of the task, also making it more akin to what might occur in everyday life. The aim was to reduce the amount of planning in relation to the trajectory of participants, such that they were more likely to apply devote less processing resources towards their choice of movement. Additionally, questionnaire measurement of social functioning and executive function was used as comparators in relation to determining the specificity of virtual reality social deficits.

2. METHOD

2.1 Participants

Twenty two patients with prefrontal cortical lesions were included in the study (9 male; 11 female; age: Mean = 40.77; S.D. = 13.34; Education years: mean = 14.27; S.D. = 2.57; National Adult Reading Test predicted IQ: Mean = 107.05; S.D. = 11.70). These patients had no history of psychiatric or major physical illness. They were categorised as to whether they had lesions impinging on the orbitofrontal (OF; n = 14), dorsolateral (DL; n = 13), or mesial (M; n = 14) regions. The patients were compared to 22 normal controls (8 male; 12 female; age: Mean = 40.82; S.D. = 13.50; Education years: mean = 15.59; S.D. = 2.84; National Adult Reading Test predicted IQ: Mean = 109.95; S.D. = 9.19).

2.2 Virtual Reality Task

A virtual bar consists of an approximately square interior with the bar at the far wall opposite the entrance door. In between the entrance door and the bar are two groups of people with a small gap between them. The test consisted of four trials in which the person had to navigate (moving using a joystick) to the bar, order drinks and return the entrance. At the beginning of each trial the participants were therefore faced with a potential direct route to the bar, although the proximity of the two groups of people would make this socially less appropriate. For the four trials, the configuration of the people was varied to depict four different scenes. In the first trial the direct path to the bar was through a gap, either side of which a couple was standing holding a conversation, depicted by their orientation and proximity to one another. In a second trial, there was a similar scene, although the avatars were sitting either side of the gap whilst conversing. These two trials were termed 'Conversation Blocking.'

The third trial showed a number of shopping bags either side of a gap and the fourth showed two people standing with their backs to one another conversing with a group of people either side of the gap forming the direct path. These two trials were termed 'Social Proximity.' Although a direct path did not directly block a conversation between protagonists, our pilot studies of normal adults suggested that it was sufficiently close to the social scenario as to be thought socially inappropriate to pursue the direct path, and the number of direct path trajectories (termed social rule violation) were approximately the same in the 'Conversational Blocking' and 'Social Proximity' conditions.

A large space existed around the central configuration for participants to walk if they decided not to take the direct path. The remainder of the room consisted of tables occupied by other avatars. There were also two avatars standing to the left of the bar and a 'bar man' standing at the cash till, behind the bar. The task was set up such that the participant moved to the bar to order the drinks and then go back to the entrance, prompting two opportunities for social violation. Sets of simple questions and tasks were developed for participants to carry out on each task and given to participants on a cue card. They could refer to the cue cards throughout the task, thus limiting loading on memory. The tasks comprised of collecting information contained in the bar environment. The aim was for the tasks to provide a distraction from over interpretation of the social task, thus encouraging spontaneous reactions to the social environment and limiting participant bias and response demands.

2.3 Questionnaire and Neuropsychological Assessments

An additional background assessment was conducted to explore the everyday activity and social functioning of the patients using the Patient Competency Rating Scale (PCRS) (Prigitano & Fordyce, 1986), based on an informants report. In addition, the executive functioning of the patients was assessed using the Controlled Oral Word Association Test (COWAT) (Benton, Hamsher & Sivan, 1994); the Hayling Test (Burgess & Shallice, 1997) and the Trail Making Test (Reiten and Wolfson, 1993).

3. ANALYSIS

3.1 Virtual Reality Task

The measure, termed the pathway error, was the number of times the patient took a direct route. Since there were two opportunities for each task for a social rule violation a potential maximum of two could be obtained for each condition. The direct route measures were collapsed for the Conversational Blocking and Social Proximity conditions, producing a mean score (scale 0-4) for each condition, with high scores indicating social inappropriateness.

For the analysis the prefrontal group were split into subgroups in an adaptation of the method described by Rowe et al (2001). In summary, they were divided into those whose lesion impinged on a specific region or otherwise as following: (1) Orbitofrontal cortex (n = 14) versus non-orbitofrontal (n = 8); (2) Mesiofrontal cortex (n = 14) versus non-mesiofrontal (n = 8); and (n = 3) Dorsolateral cortex (n = 13) versus non-dorsolateral (n = 9).

For the virtual reality data, two way ANOVA's were used to explore the data for each comparison with type of Group as between-subject factor (which included the two patient groups created by the division and the control group) and type of task (Conversational Blocking versus Social Proximity) as within-subject factors. Post-hoc analyses were appropriate were conducted to investigate differences between groups within each type of task. For this a more conservative Bonferroni corrected level of $p = 0.03$ or less was used as the threshold of significance.

3.2 Questionnaire and Neuropsychological Assessments

For the questionnaire or neuropsychological assessment data, one-way ANOVA's were used with each variable, and for data that was not normally distributed a non-parametric approach was used with the Kruskal Wallis test to analyses between group differences.

4. RESULTS

4.1 Virtual Reality Task

The pathway errors for the different comparisons are shown in Tables 1. For the analysis including the Orbitofrontal and non-orbitofrontal division there were no main effects of Group or Task. There was an interaction between the factors and this is indicative of the orbitofrontal group showing relatively greater pathway errors on the Social Proximity measure. For the analysis of the mesiofrontal and non-mesiofrontal division, a similar result was found. For the dorsolateral and non-orbitofrontal division there were no Group or Task effects, but there was a significant interaction between Group and Task. A post hoc analysis revealed that this was due to the non-dorsolateral group making being more likely to take a less socially appropriate track on the Social Proximity tasks.

Table 1. *The Pathway Error scores for the Conversational Blocking and Social Proximity Conditions, also showing the F value and levels of significance for the two-way ANOVA's.*

Orbitofrontal versus non-orbitofrontal division	**Control (n=22)**		**Orbitofrontal Group (n=14)**		**Non-orbitofrontal group (n=8)**			**F-Value**	**p-Value**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Group**	1.13	0.33
Conversational Blocking	1.82	1.62	2.50	1.79	2.13	1.64	**Level**	0.02	0.89
Social Proximity	2.32	1.67	2.79	1.58	1.25	1.75	**Levels X Groups**	3.00	0.06

Mesiofrontal versus non-mesiofrontal division	**Control (n=22)**		**Mesiofrontal Group (n=14)**		**Non-Mesiofrontal group (n=8**			**F-Value**	**p-Value**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Group**	1.13	0.87
Conversational Blocking	1.82	1.62	2.43	1.60	2.25	1.98	**Level**	0.32	0.58
Social Proximity	2.32	1.67	2.07	1.64	2.50	2.07	**Levels X Groups**	1.58	0.22

Dorsolateral versus non-dorsolateral division	**Control (n=22)**		**Dorsolateral Group (n=13)**		**Non-Dorsolateral group (n=9)**			**F-Value**	**p-Value**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Group**	1.81	0.18
Conversational Blocking	1.82	1.62	2.15	1.73	2.67	1.73	**Level**	0.53	0.47
Social Proximity	2.32	1.67	1.46	1.61	3.33	1.41	**Levels X Groups**	3.94	0.03

4.2 Questionnaire and Neuropsychological Assessments

The results for the PCRS and neuropsychological tests are show in Table 2, with the three patient divisions. Where the data was not normally distributed ranges are shown and a non-parametric statistical analysis applied. For the PCRS, there were no differences between the groups. For the neuropsychological tests ANOVA's showed significant differences for all types of group comparison, the data indicating impairments in the different patient groups. For the Hayling Test (summary Scaled Score) there were again impairments throughout the patient group. On the Trail Making Test, however, there were no such differences.

Table 2. *Questionnaire and Neuropsychological Assessment Results.*

	Control (n=22)		Orbitofrontal Group (n=14)		Non-Orbitofrontal Group (n=8)		F/ H Value	Sig
	Mean/ Median	S.D./ Range	Mean/ Median	S. D./ Range	Mean/ Median	S. D./ Range		
PCRS Total	140.00	117-150	136.50	101-147	134.50	123-145	0.64	0.43
COWAT	51.32	13.32	38.00	13.36	27.50	16.51	4.91	0.01
Hayling	6.00	5-8	6.00	5-8	6.0	4-8	6.46	0.04
Trails A	31.50	19-70	30.50	16-45	38.50	21-95	3.71	0.33
Trails B	65.5	43-119	67.50	46-120	82.50	67-165	3.71	0.16

	Control (n=22)		Mesiofrontal Group (n=14)		Non-mesiofrontal Group (n=8)		F/ H Value	Sig
	Mean/ Median	S.D./ Range	Mean/ Median	S. D./ Range	Mean/ Median	S. D./ Range		
PCRS Total	140	117-150	136	101-147	134.50	123-145	0.64	0.43
COWAT	51.32	13.32	38.38	13.56	36.71	16.62	4.95	0.01
Hayling	6.00	5-8	6.00	3-8	6.0	4-7	6.22	0.05
Trails A	31.50	19-70	31.00	16-45	34.00	23-94	1.40	0.49
Trails B	65.5	43-119	68.00	50-120	81.00	46-165	2.31	0.32

	Control (n=22)		Dorsolateral Group (n=13)		Non-dorsolateral Group (n=9)		F/ H Value	Sig
	Mean/ Median	S.D./ Range	Mean/ Median	S. D./ Range	Mean/ Median	S. D./ Range		
PCRS Total	140	117-150	134	104-145	142.00	101-147	3.21	0.20
COWAT	51.32	13.32	37.15	13.72	39.00	16.35	4.96	0.01
Hayling	6.00	5-8	6.00	4-8	6.00	3-7	7.14	0.03
Trails A	31.00	19-70	34.00	16-94	31.00	21-40	0.50	0.78
Trails B	65.5	43-119	80.00	56-165	67.00	46-83	4.25	0.12

5. DISCUSSION

The main measure was the number of times the patient took a direct route and since there were two opportunities for each task for a social rule violation a potential maximum of two could be obtained for each condition. The direct route measures were also collapsed for the Conversational Blocking and Social Proximity conditions. A further analysis comparing the orbitofrontal, non orbitofrontal and control conditions showed a trend towards an interaction between condition and group, which suggested greater social rule violation in the orbitofrontal group compared the controls, specifically in relation to the Social Proximity condition. In the analysis comparing the dorsolateral versus non-dorsolateral patients, this pattern was more pronounced but in a reversed manner, suggesting a specific deficit in patients who did not have dorsolateral lesions, in other words those whose lesions were involving orbitofrontal and mesiofrontal regions. Hence, the results are in keeping with the main prediction, that these regions would be associated with social rule violations relating to personal space, in this case the effect occurring for the Social Proximity condition.

A subsidiary question is why the less appropriate behaviour was found only for the Social Proximity condition? One possible explanation for this result is that this is a more subtle test of the ability to avoid social rule violations. Where two people are facing each other in close proximity, for some people, this scenario is less socially ambiguous and it is possible the social consequences of going between facing people is easier to detect. This difference may not be detected in the control participants, where a variety of other factors may determine a decision to go through the direct route, hence the pathway errors are approximately the same. In the patient group, however, those prone to social rule violations will tend to express this in relation to the more ambiguous Social Proximity condition.

The virtual reality task results can be compared to the PCRS to measure everyday activity and social functioning. This questionnaire proved not sufficiently sensitive to detect changes in the patient group, despite these patient having known difficulties in everyday life. It is possible that Virtual Reality techniques may detect social impairments by engaging the patient in social activity, which may prove more valid than relying on a questionnaire technique with informants. In contrast, neuropsychological deficits relating to executive functioning were measurable in the patient group and these suggest impairments in verbal fluency, generativity and response inhibition.

6. CONCLUSION

In conclusion, this is the first study using virtual reality to assess social functioning in patients with acquired brain lesions. It shows that a simple virtual reality procedure that measures judgement of interpersonal space in social situations is sufficiently sensitivity to measure subtle differences in social functioning in patients with frontal lobe neurosurgical lesions. This was in the absence of the ability of informant questionnaires showing such differences. Hence, virtual reality may provide a sensitive method for measuring social deficit in brain damaged patients with subtle social cognitive impairments that cannot be detected using more 'traditional' questionnaire methods. It also supports the notion that social impairment measured in this fashion is more likely to be associated with orbitofrontal or mesiofrontal brain lesions.

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7. REFERENCES

A Benton, AB Sivan and K Hamsher, NR Varney and O Spreen (1994), *Contributions to Neuropsychological Assessment: A clinical Manual 2nd Edition.* Oxford University Press, New York.

J Barrash, D Tranel and SW Anderson (2000), Acquired personality disturbances associated with bilateral damage to the ventromedial prefrontal region. *Dev. Psychol,* **18**, 355-381.

PW Burgess and T Shallice (1997), T*he Hayling and Brixton Tests*. Thames Valley Test Company, Bury St Edmunds, UK.

J Hornak, J O'Doherty, J Bramham, ET Rolls, RG Morris, PR Bullock and CE Polkey (2004), Reward-related reversal learning after surgical excisions in orbitofrontal and dorsolateral prefrontal cortex in humans*. Jn Cog Neurosc*, **16**(3), 463-478.

S Parsons, P Mitchell and A Leonard (2004), The use and understanding of virtual environments by adolescents with autistic spectrum disorders. *Jn. Aut. Dev. Disord*., **9**(1), 95-117.

RG Morris, J Bramham and A Rowe (2003), Social Cognition following prefrontal cortical lesions. In *The Social Brain* (M. Brune, Ed), John Wiley Press, Chichester.

GP Prigitano and DJ Fordyce (1986), Cognitive dysfunction and psychosocial adjustment after brain injury. In *Neuropsychological Rehabilitation after Brain Injury* (GP Prigatano, DJ Fordyce, HK Zeiner, JR Rouche, M Pepping and BC Woods, Eds), John Hopkins University Press, Baltimore.

RM Reitan and D Wolfson (1993), The Halstead-Reitan Neuropsychological Test Battery: Theory and Clinical Interpretation 2nd Edition. Neuropsychological Press, Tucson, Arizona.

JL Saver and AR Damasio (1991), Preserved access and processing of social knowledge in a patient with acquired sociopathy due to ventromedial frontal damage. *Neuropsychologia*, **29**(12), 1241-1249.