Impairment of spatial cognitive function with preservation of verbal performance during spatial disorientation

M. A. Gresty[1]
Sarah Waters[1]
A. Bray[1]
Karen Bunday[1]
J. F. Golding[2]

[1] Department of Neuro-Otology, Division of Neuroscience & Psychological Medicine, Imperial College London
[2] Department of Psychology, School of Social Sciences, Humanities and Languages, University of Westminster

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Gresty MA[1], Waters Sarah[1], Bray A[1], Bunday Karen[1], Golding JF[2].

1 Department of Neuro-Otology, Division of Neuroscience & Psychological Medicine, Imperial College London, London W6 8RF, UK.
2 Dept of Psychology, University of Westminster London W1B 2UW, UK.

Correspondence: M Gresty. Department of Neuro-Otology, Division of Neuroscience & Psychological Medicine, Imperial College London, London W6 8RF, UK.
tels: 00 44 (0)208 846 7634; 00 44 (0) 7711 088 567; m.gresty@imperial.ac.uk

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Abstract

Spatial disorientation, which is responsible for up to 30% of aircraft accidents causes impairment of cognitive function which may further compromise a pilot's ability to think his way out of the situation and regain control [1,]. The functional-anatomical separation of spatial and verbal processing [10,11] raises the possibility of selective interference between the task of resolving spatial disorientation and the ability to perform concurrent spatial, as opposed to verbal, secondary tasks. We report for the first time a degradation of spatial task performance with preservation of verbal performance when subjects in a simulator are disoriented by conflict between self-motion and visual flow in the view of the external environment.

Introduction

Cognitive impairment as a consequence of spatial disorientation in flight is thought to be a contributing factor in aircraft accidents [1] and is a reported symptom in patients who suffer from vertigo and imbalance [2]. Disorientation induced experimentally by creating conflicts between visual, vestibular and somatic signals of motion and disorientation experienced in real flight and flight simulation have been shown to degrade performance on a variety of cognitive tasks [3(historical review),4-8]. In such studies the subject is usually aware of the potential for disorientation. The observed decrements in performance have affected both verbally and spatially loaded tasks and accordingly, have been attributed to the draw on general attentional resources [5,7,9] and especially in the case of aviators, heightened anxiety. The intriguing possibility, suggested by functional-anatomical divisions between spatial and verbal processing [10,11] that spatial disorientation may have selective impact on spatial task resources, hitherto has not been demonstrated.

We report a selective disruption of spatial tasks in comparison with verbal performance during conflicting visual and vestibular-somatic cues to movement in space. The experiment exploits an incidental observation made in our laboratory that subjects exposed to pitching movements in a flight simulator with a simulated view of the external world moving in inverse phase (ie when tilting backwards, head-up they see the ground appear and when tilting forwards, face-down they see the sky appear) remain unaware of conflict. In addition to the obvious cognitive conflict between orientational cues, this paradigm brings the visually driven, pursuit and optokinetic, reflex eye movements in opposition to the vestibular-ocular reflexes (a 'visual-vestibular conflict'). Moreover, the paradigm facilitates the study of behaviour under cognitive and sensory conflict within spatial orientation of which the subject is unaware and without provoking anxiety.

Methods

Motion and Visual Simulation

The subject was seated, restrained by a harness in a single seat flight simulator which was either stationary or oscillated about upright in pitch (± 20° peak; 0.2Hz. The 'pilot' viewed a monitor which displayed a real time video image of the external world comprising park, buildings, horizon and sky, as if looking ahead through the cockpit canopy. The image was generated by an external camera viewing through a bi-axial mirror galvanometer and could be oscillated vertically or horizontally with the same motion parameters as the simulator. All other external views were occluded.

Motion Conditions

The motion conditions (Stationary, Veridical, Inverse, Orthogonal) under which task performance was evaluated are shown in figure 1.

Spatial and Verbal Tasks

The cognitive and spatial tasks were Brook's matrices [12] presented by computer. In the spatial task the subject imagined a 5x5 matrix. He then heard 7 sentences defining sequential squares, 1-7, forming a path through the matrix with [2,2] always starting square 1; eg 'in the next square to the right, put a two'. At the end of the sequence he replicated the matrix on paper. In the verbal Brook's task the subject heard 5 similar sentences but containing inappropriate words in place of right/left/up/down; eg 'in the next square to the ***slow*** put a 2'. The task was verbally to reproduce the inappropriate words in correct order.

Design

Twenty subjects (13 males), aged (20-31) gave their informed consent to the study. Between subjects the order of the 4 conditions (S, V, I, O) was allocated according to a Latin square balanced for carry-over giving 5 repetitions of the square over the 20 subjects. Each subject undertook a particular Latin sequence 6 times; 3 sets whilst performing the spatial and 3 performing the verbal task. Sets of tasks were delivered in alternation.

Subjective ratings of malaise

Immediately after the final condition subjects rated symptoms of malaise on the Simulator Sickness Questionnaire 'SSQ' [13] to assess the possibility that they developed symptoms during testing which might have affected performance.

Results

Only 2 subjects reported the inverse motion as being 'odd' when questioned after the experiment but could not identify why it was odd. No subjects reported developing malaise according to SSQ ratings.

There was great inter-subject variability in performance ranging from 0 errors across all tasks to 50% errors. Errors on tasks were calculated as percentages. Since verbal error rates were approximately 3 times higher than spatial error rates, all verbal error percentage scores were normalised to the average percentage of spatial errors obtained for the control condition (multiplication factor x0.375).

After normalisation there were no differences in either means or SDs for 'veridical' or 'orthogonal' conditions. Mean and SDs of verbal errors were remarkably similar for all conditions and this was confirmed by ANOVA. The mean for spatial errors for the 'inverted' condition appeared higher but failed to attain significance. However the variance of spatial error during 'inverted' was clearly greater (fig 1) than verbal error, or for that matter all other conditions. Comparison of variances (spatial vs verbal for inverted motion) using Pitman's test for differences in variability in paired data [14] showed the difference in variance to be highly significant (rho= 0.75, n=20 $p<0.001$).

Eighteen subjects made errors, hence were task sensitive. The increase in variability of performance on spatial tasks in the Inverse condition was attributable to 6 of these (30%) making more errors than their typical performance in the other conditions.

Discussion

The results demonstrate a selective interference of the Inverted condition with spatial, but not verbal, cognitive tasks causing a highly significant increase in the variability of error rate. The interference occurred in approximately 1/3rd of subjects sampled, reflecting individual differences in susceptibility which could have implications both for flight-personnel selection and markers for vulnerability in patients.

Anxiety has been implicated in the impairment of cognition in disoriented pilots who are stressed by the threat of loss of control of their aircraft. Anxiety was not present in our subjects in any of the conditions according to their SSQ ratings [13].

Whereas vestibular driven and pursuit eye movements would be synergistic in the Veridical condition which demanded a slow phase eye movement of 25°/s, the Inverse and Orthogonal conditions required suppression of the vestibular-ocular reflex with vectored eye movements of 50°/s, and 35°/s (oblique) respectively for stable viewing of the video image. Therefore, the effect on spatial tasks of spatial disorientation could be attributable to slightly higher oculomotor demands of the Inverse condition. This explanation is unlikely since the velocity of visual motion in more compelling full field viewing situations is unrelated to error rates on Brook's tasks [7]. The alternative explanation, which we favour, is that higher spatial task errors are due to demands on spatial cognitive processing which may be occupied by attempting to resolve the mismatched visual and vestibular-somatic signals of motion.

Obvious conflict of motion signals during orthogonal self and visual motion did not lead to increased errors on tasks. Perhaps the sensory input, once identified as meaningless, can be quarantined so that it does not draw on attentional resources. Although not consciously appreciated, the 'Inverse' condition does have a negative impact since it is nauseogenic if exposure is sustained [15] which is evidence for the impact of sensory conflict. It may be the lack of conscious appreciation of mismatch by the subject which renders him vulnerable to spatial error, since the mismatched input cannot be quarantined and excluded from drawing on attentional resources.

The observed individual differences in susceptibility to disorientation are typical of human factors analysis of disorientation and spatial performance and could imply that the tasks we deployed have potential value for screening personnel.

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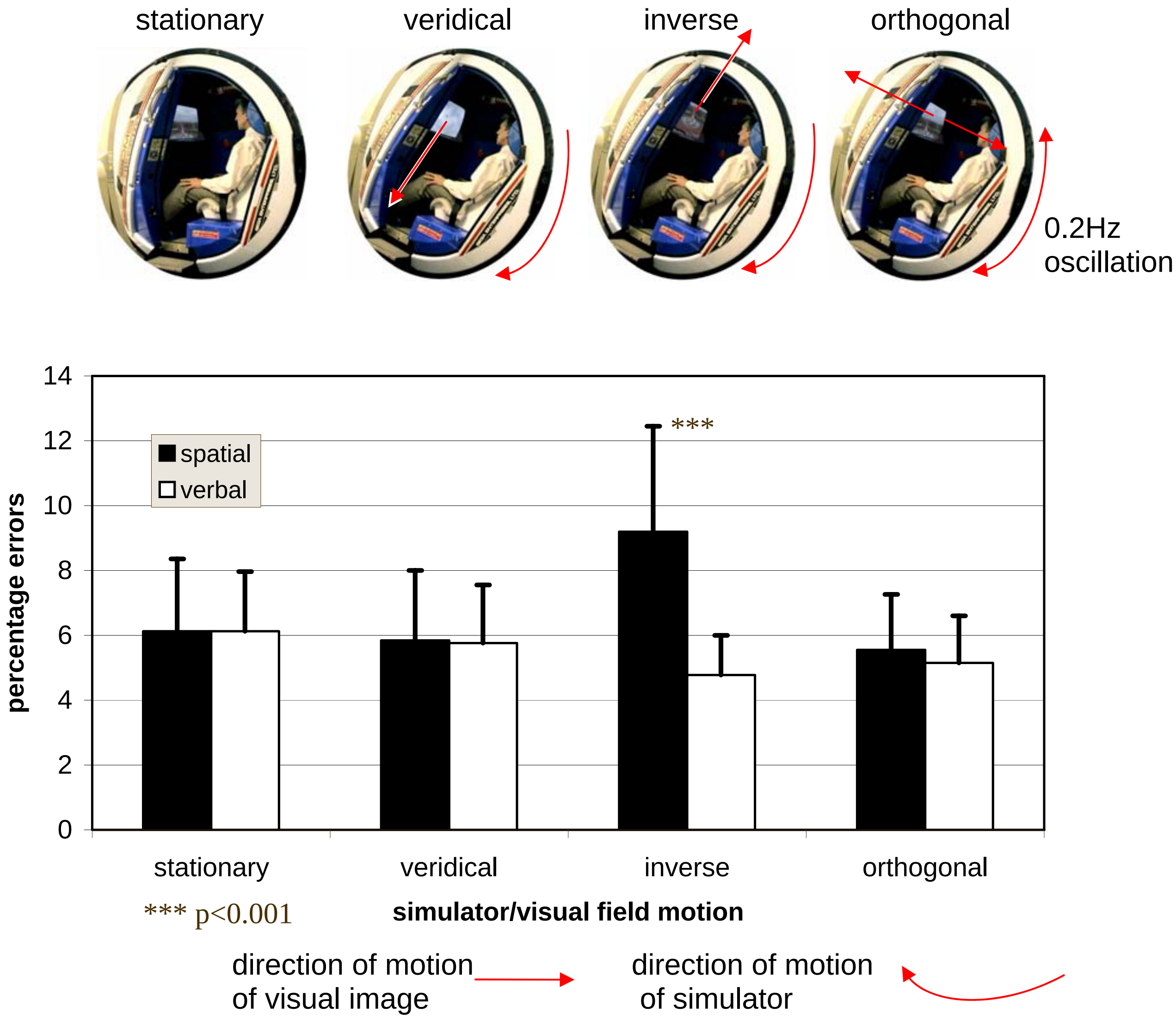
Figure 1

Mean percentage errors +SEs on Brook's spatial and verbal tasks under different conditions of disorienting motion simulation. n=20 subjects



Motion Conditions

C: Control: subject upright, simulator stationary; video image of the environment stationary.

V: Veridical: simulator oscillating. Video image oscillating appropriately (ie pilot tilts back head up and sees sky; tilts forwards head down and sees the ground).

I: Inverse: simulator oscillating with video image oscillating in inverse-phase.

O: Orthogonal: simulator oscillated in pitch whilst video image oscillated in yaw (horizontal motion of exterior view).

Correlations

		DIF	SUM
DIF	Pearson Correlation	1.000	.752
	Sig. (2-tailed)	.	.000
	N	20	20
SUM	Pearson Correlation	.752	1.000
	Sig. (2-tailed)	.000	.
	N	20	20

** Correlation is significant at the 0.01 level (2-tailed).

Descriptive Statistics

	N	**Minimum**	**Maximum**	**Mean**		**Std. Deviation**
	Statistic	**Statistic**	**Statistic**	**Statistic**	**Std. Error**	**Statistic**
CS	**20**	**.00**	**38.83**	**6.1205**	**2.2346**	**9.9934**
NCV	**20**	**.00**	**29.38**	**6.1199**	**1.8434**	**8.2441**
VS	**20**	**.00**	**28.00**	**5.8415**	**2.1571**	**9.6470**
NVV	**20**	**.00**	**26.95**	**5.7522**	**1.7973**	**8.0380**
IS	**20**	**.00**	**50.00**	**9.2005**	**3.2510**	**14.5391**
NIV	**20**	**.00**	**17.15**	**4.7686**	**1.2239**	**5.4733**
HS	**20**	**.00**	**27.83**	**5.5505**	**1.7115**	**7.6538**
NHV	**20**	**.00**	**22.03**	**5.1426**	**1.4531**	**6.4984**