The Peculiarities of Spatial Orientation of Person in Conditions of G-Influences

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SUMMARY

Six test subjects were subjected to lateral (+$\mathbf{G_y}$) and longitudinal-lateral (+$\mathbf{G_z}$/+$\mathbf{G_y}$) accelerations in a centrifuge with a rotation radius of 6.55 m. During rotation, test subjects were instructed to indicate the position of subjective visual vertical.

Results of this study demonstrated that during exposure to +$\mathbf{G_y}$ and +$\mathbf{G_z}$/+$\mathbf{G_y}$ accelerations, the direction of the indicated subjective vertical approached the direction of the resultant acceleration vector when the lateral component increased. This observed effect decreases with an increase of the longitudinal component of the acceleration. It was suggested that exposure to (i.e. "pulling") high lateral acceleration (up to 2-3 G_y) in highly maneuverable aircraft can hinder spatial orientation of a pilot due to this persistent illusory spatial position as reported above.

Our analysis showed that the process of spatial orientation under the conditions of G-load influence becomes more difficult and it is depending on the compromise between visual and vestibular-proprioceptive inputs. On account of this finding, it may be proposed that under conditions of G-load influence, pilots that rely primarily on visual perception may be exposed to higher risk of spatial disorientation.

INTRODUCTION

Presently, investigators pay ever-growing attention to the methods of correction of perceptual illusions of spatial attitude, limited to the influence of linear accelerations (G-loads), where the resulting gravitational-inertial vector deviates from the longitudinal body (z) axis only. The motivation of this investigation is driven by the possibility of increased pilot spatial disorientation in superagile aircraft such as the Su-30. During superagile flight, the pilot is exposed to lateral G_y and transverse G_x , in addition to the longitudinal G_z-forces.

The inadequacy of the vestibular-proprioceptive apparatus [4] under altered gravitoinertial environments causes the appearance of a wide spectrum of spatial disorientation illusions of different character and expressions (for example, illusion of banking, diving, pitching-up, inverted position etc). These illusions exert aversive effects on the pilot's reliability, as they are prone to exert instinctive reaction to these erroneous cues. In addition it is very difficult to correct for illusions of vestibular origin (for example,

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illusion of contra-rotating) or visual illusions [5]. These illusions, classified as somatogravic and oculogravic illusions, may essentially degrade the pilot's spatial orientation process when flying with the new generation thrust-vectored aircraft.

METHODS

General: The general method for this series of experiments was to measure the subject's perceived orientation while he was at steady state G level. Details regarding the equipment as well as the motivation and method for each phase of the experiment are as follows. Six subjects were exposed to lateral ($+\mathbf{G_y}$) and longitudinal-lateral ($+\mathbf{G_z}/+\mathbf{G_y}$) accelerations, in a 6.55-meter in radius man-rated centrifuge located at the SSRTI MM RF MD, Moscow. The G was imposed by the rotation of centrifuge and "auto-vectoring" of the gondola such that the resultant G vector acted along the lateral or longitudinal-lateral directions with respect to the seated subject inside the gondola. Test subjects were positioned in a seat similar to that in the MIG 29 equipped with two lateral control sticks and with the back inclined at 30° from vertical. The subject was restrained with a five-point harness, and provided G protection with a standard anti G-suit. Subjects also wore a standard issue flight helmet and oxygen mask.

Subjects: Six male, aged 19-28 years of age, employed at the SSRTI MM RF MD volunteered as subjects for this study. The aim and procedures of the experiments were explained, and they were informed that they would have sensations of their spatial co-ordinates during the experiment. They were free to withdraw from the study at any time without reduction in remuneration. Each subject gave general consent and signed the specified documents at each session of the experiment. The protocol was authorized by the Director General of the SSRTI MM. None of the subjects reported any medical problems and all presented with normal vestibular functions. All subjects were assigned to both Experiment 1 and Experiment 2.

Magnitude estimation of rolling illusion evoked by lateral ($+\mathbf{G_y}$) *and longitudinal-lateral* ($+\mathbf{G_z}/+\mathbf{G_y}$) *accelerations:* We used the methods of subjective visual vertical (SVV) and subjective psychometric vertical (SPV) to estimate the effects of the acceleration and the change of the centrifuge gondola position in the static condition.

The equipment used in measuring the Magnitude of Rolling Illusion (MRI) by SVV/SPV is as follows. In order to ensure the safety of the subject during the experiment, SVV method was used [1, 8]. A cross-shaped contour in a head-up display projected to infinity (horizontal component is 10 cm; vertical component is 5 cm) at a distance of 50 cm in front of the subject was mounted in the gondola cockpit. Standard lighting was provided for all conditions. The changes of the contour attitude depend on the subject's strength exerted on the control sticks laterally.

The directions of the contour rotation coincide with the direction of the control-stick force (force to right - contour rotation is clockwise; force to the left - contour rotation is counterclockwise). Contour control-lability from the control-stick force coincided with the following conditions:

$$dP/d_{\omega} = 0{,}362\ kGs/degree.\ s^{-1};\ \ P_{max.} = 31{,}1\ kGs;\ \omega_{max.} = 1{,}5\ degree.\ s^{-1},\ \text{where:}$$

P - control-stick force, ω - contour rotation angular velocity.

Initially, contour under all experimental conditions was given in the position when its vertical component coincided with the cockpit vertical axis, and the subject's task was to direct it in the position of the subjective visual vertical. At the moment of ascertainment, the subject noted by pressing the button on the control stick and during the next 10-second graphical registration of illusory banking values relative to the initial situation was recorded for off-line data analysis.

A number of control experiments were conducted. Before each G-load influence the subject performed an analogous task during cockpit right banking under static conditions (γ = 15, 30, 45, 60, 75, 90^0) with the velocity of banking at $5^0 sec^{-1}$. Cockpit banking value was randomized for each subject to avoid learning effect.

Method of SPV was used in the experiments where SVV method cannot be employed (for example, when the position of subjects' hands rested on their knees or when the cockpit darkens). With this aim, after each experimental influence the subject noted their subjective position of the vertical line according to a psychometric scale using a vertical semicircle, on which the subject mentally putting himself into the noted point of count (vertical line), pointed value of vertical line on semicircle. The value was measured in degrees relatively to the initial value (coinciding with longitudinal axis of body). The significance of the SPV method was checked under static conditions and G-load influence with simultaneous use of SPV and SPV methods (the latter was the referent method).

In order to provide a standardized analysis of the results, the interpretation of G_Y, G_X, G_Z influencing were compared to the longitudinal, transverse and lateral (G^0_z, G^0_x, G^0_y) load components of the anatomical position of the otoliths. In addition the interpretation is also based on the spatial position of the head (i.e. the angle of inclination, bending, rotation).

Training: Prior to each experiment, the standard G-profiles was given to each subject twice at intervals of more than 1 day. The subjects were required to score the MRI from the second trial on, before they were informed that the stimuli were identical.

Experiment 1

The aim of this experiment was to study the magnitude of roll illusion (MRI) in human spatial orientation under lateral and longitudinal-lateral acceleration influence. The subject was exposed to static conditions and was exposed to the standard G-profiles twice to estimate the MRI by SVV method. The main G-influence profiles were **+G_y** = 0,5; 1,0: 2,0; 3,0 and 3,5 units; and after a 5 min rest, **+G_z/+G_y** = 1,9/1,2; 2,4/2,0, 3,0/2,9 units. In addition, the studies were performed under a static roll of the gondola of 15, 30, 45, 60, 75 and 90°. The duration of the G level last about 30 second. The MRI testing was performed after 12 second. The 12-second stabilization period allowed the dynamics of the semicircular canals to dampen out as their contribution to attitude perception was not a part of this research. Each subject participated in 2 experimental sessions. The combination of the parameters and G-profiles of the test was different in each session, and the order was randomly arranged. The experimental sessions were held at intervals of more than 1 day.

Experiment 2

The aim of this experiment was to study the interaction of visual and vestibular-proprioceptive sensory systems to human spatial orientation with respect to G-lateral and longitudinal-lateral G influence. In order to stimulate tactile-proprioceptive and visual afferent information the investigation was conducted in the following experimental conditions: **A** — binocular vision, hands on the arm-rests of seat, **B** — monocular vision, hands on the arm-rests of seat, **C** — binocular vision, hands on the knees, **D** — eyes are closed, hands on the knees. The main G-influence parameters were **+G_y** = 1,0 and 2,0 units; **+G_z/+G_y** = 3,0/2,9 units after a 5-min rest. In addition the studies were performed under a static roll of the gondola at — 15, 45 and 75°. In condition A SVV and SPV methods were used, but in conditions **B**, **C** and **D -** only SPV method was used. Each subject participated in 1 experimental session. The combination of the G-profiles of the test was different in each session, and the order was randomly arranged. The experimental sessions were held at intervals of more than 1 d.

Statistical Analysis: To examine the stability of the MRI measurements, we examined whether MRI changed during the course of the trials. A regression line was fitted to the relationship between the MRI values and the order of trials by the method of least squares, and the significance of the gradient of the estimated regression line was tested by F-test (analysis of variance: ANOVA).

RESULTS AND DISCUSSION.

The results of the SVV measured at **+G_y** and **+G_z/+G_y** loads influence **(Experiment 1)** are illustrated in **Fig.1.** The results show that in conditions of +**G_y** and **+G_z/+G_y** load influence, subject indicated subjective vertical, together with the increase of lateral component, that coincides with the direction of resulting force vector. This effect decreases with the increase of longitudinal component of G loads. According to the given mechanism the creation of subjective vertical is accompanied by the appearance of expressed and firm rolling illusion, which is at an average 17.2 ± 4.5^0; 33.4 ± 7.1^0; 56.4 ± 12.1^0 during the influence corresponding to $+\mathbf{G_y}$ = 0.5;1.0 and 2.0 unit that could affect pilot spatial orientation in flight.

From this information it is apparent that the rolling illusion at lateral loads influence increased with the increase of lateral tangential component in otolith plane **(G^0y)**, and it confirms the main mechanism of otolithic irritation (the influence of tangential force removal). The character of this dependency in general coincides with logarithmic (Weber-Fechner) or power (Stevens) laws «stimulus-sensation» for wide range of subjective reactions [6, 7]. At the same time, at $\mathbf{G^0_y}$ = 0,5; 1,0; 2,0 units SVV meanings were lower than resulting vector deviation (**G^0y**) at the average for 81; 47; 15 % accordingly, but at $+\mathbf{G^0_y}$ = 3,0 and 3,5 units they practically coincided.

As illustrated in **Fig. 1.**, $+\mathbf{G_z}/+\mathbf{G_y}$ loads influence were also accompanied by rolling illusion increase according to $\mathbf{G^0_y}$ component increase, nevertheless, significantly lower than the analogous interpretation of $\mathbf{G^0_y}$ in conditions of lateral loads influence. Even in $\mathbf{G^0_y}$ lateral component of more than 2.5 units, SVV indications were vector deviated (not shown in Fig 1) for 30% and 17% accordingly.

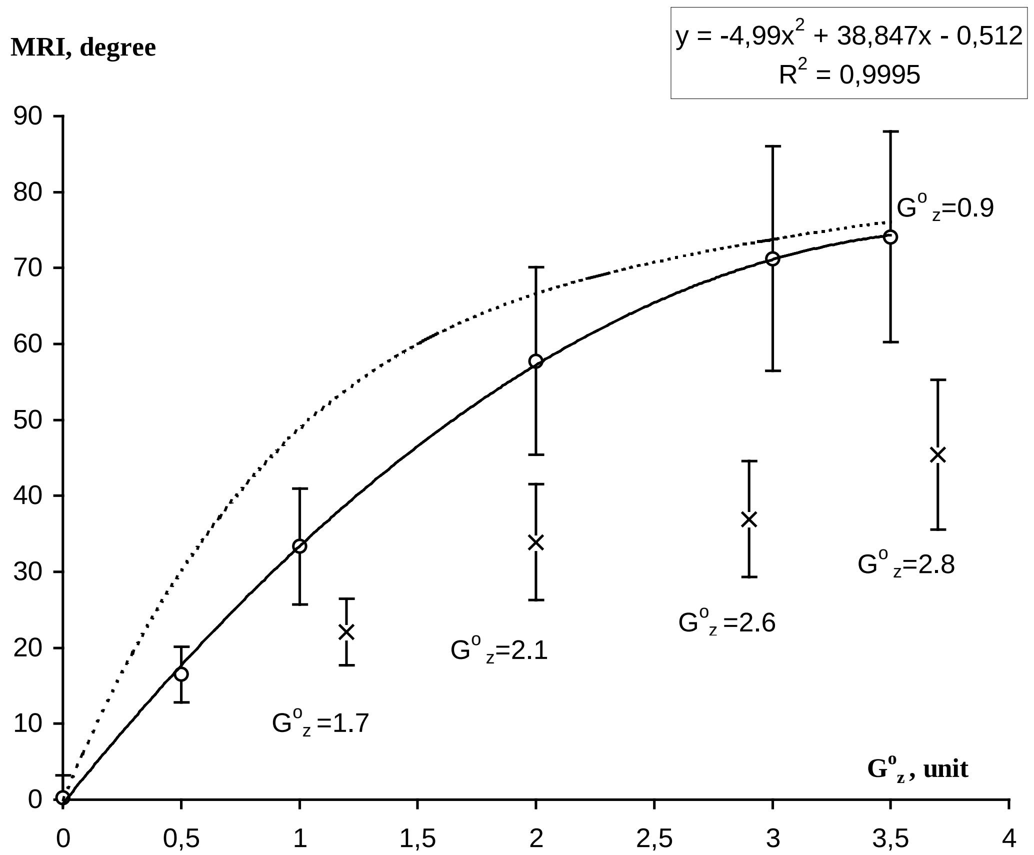

Fig. 1. The meaning of rolling illusions (entire line) and deviations of resulting gravitoinertial vector (dotted line) depending on load lateral component value at the influence of lateral (o) and combinated lateral-longitudinal (x) loads.
(M ± S.E.; n = 12). The notes are in the text.

The results from **Experiment 2** show that, in general, the difficult compromise between stimuli under conditions of sensory conflict is an individually dependant characteristic, which could be termed as “preferable modality of perception” [2].

Under static roll of the gondola, the differences observed between a subjective roll value using the SPV-method under various experimental conditions were absent. Under G-exposure (**see Fig. 2.**) the degree of MRI on the basis of SPV-indices and subjective values changed according to experimental conditions with marked individual features. In 4 subjects with eyes opened, the transfer of hands from armrests to knee was accompanied by a MRI-decrease, especially under $\mathbf{+G_y}$ = 2,0 units. With eyes closed, degree of MRI did not change. In two subjects the opposite situation was observed. The transfer of hands from armrests to knees under the eyes opened condition was not accompanied by a change in the roll illusion, but with the eyes closed, a significant increase of roll illusion was observed, especially under $\mathbf{+G_y}$ = 2,0 units and $\mathbf{+G_z/+G_y}$ = 3,0/2,9 units.

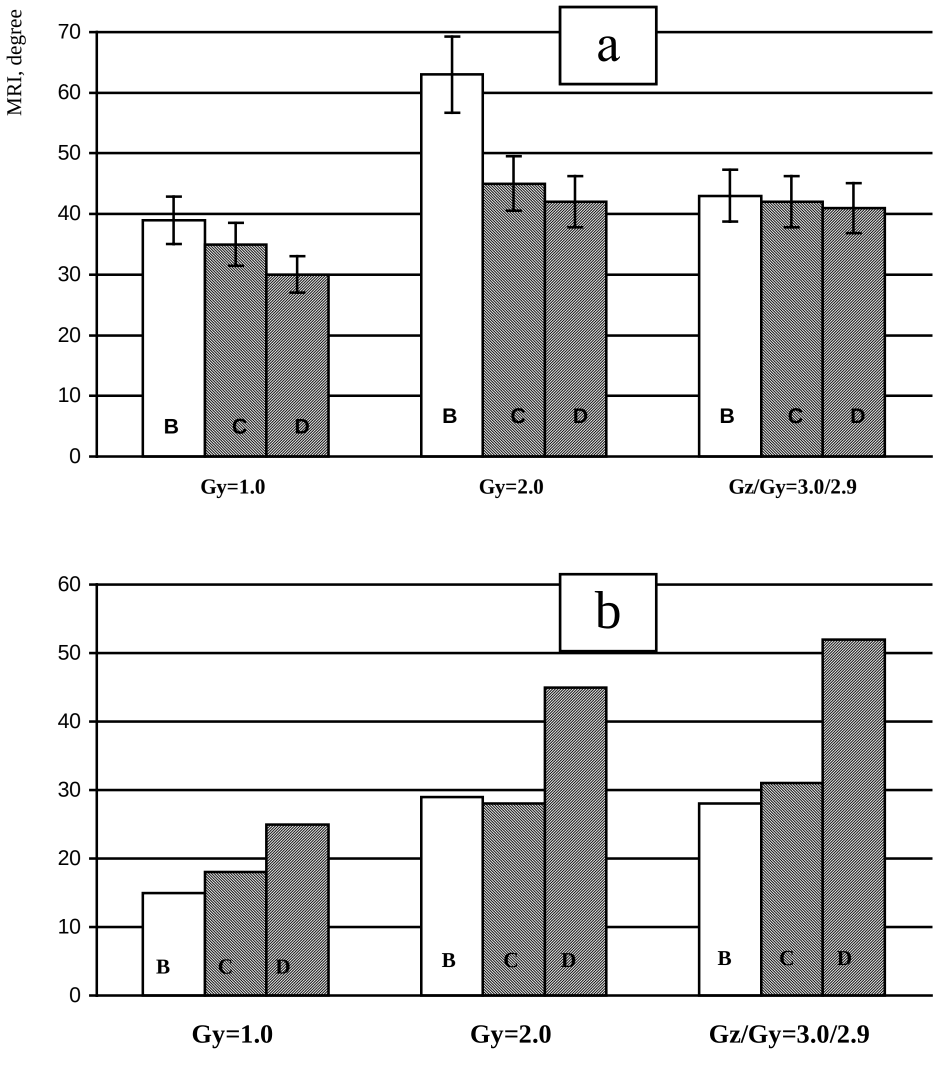

Fig. 2. Marked rolling illusion (on SPV method) at $+G_y$ and $+G_z/+G_y$ loads influence depending on experiment conditions.

Note: «a» (M±m; n=4), «b» (M; n=2), the rest notes are in the text.

The increase of MRI was accompanied by subjective reports after the trials. Subjects described their sensations as “sense of endless roll”, “constant rotation to the right”, “impossible to determine the spatial attitude”, “expectation of impact on the floor”. Specified groups of subjects varied on the MRI-manifestation under G-exposure in the control experimental conditions (A). In the first group the MRI-manifestation has practically corresponded with the magnitude of deviation of resulting gravitoinertial vector and was on the average of 2-3 times higher, than in the second group.

Our results can be interpreted in terms of the availability of individual preference of perception modality. Realization of complex compromise between stimuli in the conditions of sensory conflict is an individual characteristic, which is termed as “preferable modality of perception” [2, 3]. Some subjects prefer vestibular-proprioceptive information, to the detriment of visual one, but others — visual information, to the detriment of vestibular-proprioceptive. Under $\pm \mathbf{G_y}$ and $+\mathbf{G_z}/\mathbf{G_y}$-exposures, the probability of spatial orientation disturbance could be expected by persons with “preferable visual modality of perception”, in comparison with the persons having “preferable vestibular-proprioceptive modality of perception”.

Our analysis shows that the process of spatial orientation under conditions of G-load influence depends on individual peculiarities of a compromise between visual and vestibular-proprioceptive information. The ultimate definition of subjective spatial co-ordinates is different among persons with vestibular-proprioception and those with visual modality of perception. In the first case the illusions are expressed, but changed little in the presence and character of visual reference-points, and in the second case - the illusions are expressed a little with the presence of adequate visual reference-points and increased greatly in their absence. Taking the above into account, it is proposed that in conditions of G-load influence because of the lability of subjective spatial co-ordinates, pilots with visual modality of perception may have higher risk of spatial disorientation.

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