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THE MARS500-EXPERIMENT "6DF" – A TEACHING AND TESTING APPROACH – FIRST RESULTS

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ABSTRACT

Manual control of moving objects in weightlessness requires the operator to consider six degrees of freedom (6df) for simultaneous movement. This paper presents the current state of an on-going project aimed at the development and evaluation of a self-sufficient education and training tool with embedded psycho-diagnostic features. The learning program is presently still at the level of a prototype. Training success was assessed applying after the training phase a former version of the Russian standard trainer software for docking (experiment PILOT) with a sophisticated analysis of performance. The first implementation of this tool was tested during the 105-day pre-study phase and the 520-day phase of the Mars500 project (Moscow, IMBP). In both study phases, three of the six subjects were untrained in docking maneuvers. During the 105-day phase, two of the three subjects became successful in docking training. In the 520-day phase, the subjects discontinued using the 6df-trainer already after 200 days, and resumed with the Russian docking trainer. Only one of them was reliably successful in docking. However, the results are promising enough to continue this ambitious development, including the embedded testing of fundamental psychological aspects.

I. INTRODUCTION

The manual control of objects in weightlessness requires the consideration of six degrees of freedom. For comparison, driving a car needs the simultaneous control of two degrees of freedom: direction (turn on vertical, here y-axis) and speed (along x-axis). In the open space object orientation and object flight path are decoupled. This challenge is unusual under terrestrial conditions. Humans cannot prepared by usual educational development (including flying or diving). The control of any object under these conditions requires a higher degree of complexity in perception, cognition and motor multitasking. Manzey et al. (1998a,b) demonstrated that deficits in certain periods of the space flight (initial phase) are already visible in an unstable tracking with one degree of freedom. A more sophisticated monitoring of tracking and control skills of astronauts with increasing degrees of difficulty would provide better understanding of space flight's short-term and long-term effects on mental performance and motor control.

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A more realistic task type should have a higher degree of ecological validity for astronautic requirements and therefore enhance subjects motivation. On one hand, this characterizes the task type itself as an excellent model for future psychological research. On the other hand, the practical relevance of the topic became evident in research of Salnitski et al. (2001a, b). They demonstrated that the reliability of skills (docking) which had exclusively been trained in simulators but have never been practiced in reality ("artificial skills") decreases even in well trained astronauts after a period longer than three months of space flight without training. One could argue that docking can be realized more reliably in an exclusively automated way. The Russian practice rejects that assumption. Hand controlled docking was required during the MIR period, when the automatic docking failed due to missing sensory inputs. Another typical situation for a required manual re-docking flight was the expected approach of the shuttle to the space station (MIR and ISS) and the docking terminal was occupied by a Progress transport space craft which had to be re-docked onto another docking terminal. For these re-docking maneuvers, no automated programs existed.

There is also a psychological aspect to be considered. Its common experience that not each pilot of an aircraft would permit his plane to land automatically, if he could not land it under own hand control. However, conducting a manual docking in reality it is usually the first and only trial for the respective astronaut. This could be compared with an airline pilot, running his very first air plane landing with hundreds of passengers on board. There is a considerably high risk to be carried by the operator. It's obvious that "strain" plays a critical role in such circumstances. It is a particularity of the task that performance and actual strain will be monitored together during skill acquisition and refreshment and possibly also during a real docking situation(Salnitski et al. 1998).

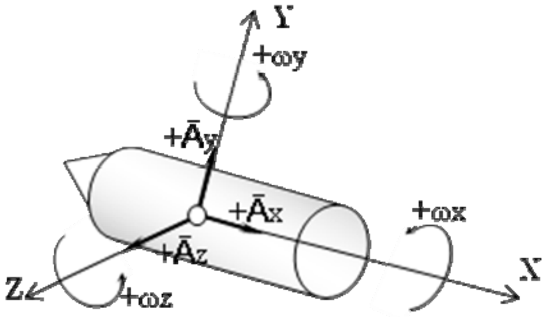

Figure 1) Six degrees of freedom (Russian Coordinates System in Space):
Āx; **Ā**y; **Ā**z - linear acceleration effects by moving the left hand control for translation of the object in space.
ωx; ωy; ωz - angle acceleration effects by moving the right hand control for orientation of the object in space.

Assuming an increasing duration and complexity of space stations or long-term missions as to Mars the role of manually controlled moving and docking in space will grow. Taking into consideration that docking a spacecraft can hardly be learnt by trial and error, as demonstrated by data of the SFINCSS study (Salnitski et al. 2004), an autonomous computerized training program would be a helpful means for acquisition, refreshment and maintenance of this required space skill. Especially with regard to an extended long-term interplanetary flight a validated and reliable "6df" trainer could be of great value. However, also astronauts/cosmonauts on earth during their studies and education may be educated more effectively if their learning of the psychologically fundamental skills is supported by a computerized training.

There is a long history of learning theories. A great progress in formulation of principles was already done in the eighties within the aviation oriented research. Some of them focus on complex or "high-performance" skills (Schneider (1985). Others focus on the learning style, for example part-task vs. whole task training (Wightman et al. 1985). These authors define high-performance skills as ones in which more than 100 hours of training are required, a substantial number of individuals fail to develop proficiency and the performance of the expert is qualitatively different from that of the novice. The space craft docking skill fulfills all three criteria. It was shown that generalization from simple skill task trainings applied to the high-performance skills can be fallacious. Six fallacies were detected: 1: Practice makes perfect; repeated performance of a task will automatically improve the performance (Chase et al. 1981); 2: Training of the total skill is the best method to train the final execution (Hopkins, 1975; Caro 1973); 3: Learning is intrinsically enjoyable per se; extrinsic motivation is not necessary (Schneider, 1985); 4: Train for accurate performance; oppositely, one should train for "acceptable performance" and reliable performance under high workload conditions (LaBerge (1976); 5: Initial performance is a good predictor of trainee and training program success (Kennedy et al. 1980); 6: Once the learner has a conceptual understanding of the system, proficiency will develop in the operational setting (Schneider, 1985). It was pointed out, that complex skills need training over extended periods of time, it's beneficial to train more extended critical components of the tasks and the first 100 trials are not a reliable predictor of later performance. There are principles presented for the development of training programs for high-performance skills: 1: Present information to promote consistent processing by the operator (e.g. by adaptive training); 2: Design the task to allow many trials of critical skills; 3: Do not overload temporary memory and do minimize memory decay; 4: Vary aspects of the task that vary in the operational situation; 5: Maintain active participation throughout the training; 6: Maintain high motivation throughout the training period.

This led to a concept which preferred part-task training for complex skills especially in inexperienced students (Wightman et al. 1985). Part-task training was defined as practice of a defined set of components from a whole task as a prelude to performance of that whole task (Wightman et al. 1985). Part-task procedures were shown to improve learning efficiency and to reduce costs. Special procedures of segmentation, fractionation and simplification were suggested prior procedures of reintegrating parts into the whole task.

All this must be taken into consideration for a training program for the "6df"-skill. Furthermore, the experience of our Russian colleagues point out that for different applicants different approaches are needed. So the construction of the “6df” had to be left open for new theoretical approaches and knowledge to be realized within.

This paper presents the current state and the first results of a project aiming at the development and evaluation of a self-contained psycho-diagnostic training tool which combines practical needs (training, education of important operational skills required during space flight, i.e. for manual spacecraft docking) with excellent scientific research opportunities (learning, memory, cognition, complex coordination, multi-tasking, autonomic response, emotional stress, dyadic/group structure during long term space flights). At the same time, the tool provides a high motivational component for the subjects. The project “6df” was evaluated and selected for participation in the Mars500 study (Moscow, IBMP) by ESA. The first prototype of this tool was tested during the Mars500 project to examine whether the self-sufficient method is applicable for long-term confinement and isolation. In the first step, the technical feasibility must be realized and verified. A tested, verified and successful training system would greatly enhance the safety and well being of the crew. It is advantageous to have a diagnostic tool for other psychological issues on-board that is accepted by the crew members. Insofar the Mars500 study served as a testing ground for a future space application. The hardware (6df-hand controls are analogous to the real space craft controls) as well as the prototype of a diagnostic tool (series of different 6df tasks with increasing difficulty) had been developed in cooperation with the Institute of Aerospace Medicine of the German Airforce. It is used for the assessment of basic skills and compared to air-to-air re-fueling skills in simulated and real flights with large aircraft – a quite similar terrestrial task to the space craft docking. From these basic tools a training program for autodidactic usage was further developed.

The experience that Russian experts acquired through so many years of practical work in education, training and evaluation the hand controlled docking of a space craft on a space station led to a computerized performance analysis first described by Komotski and Salnitski in 1977. This well tested scientific method for performance assessment of the Russian docking training system (Komotski et al. 1977; Salnitski et al. 1998, 2001a, b; Johannes et al. 2004) was used as gold standard measure.

II. METHOD

The Mars500 study is described in detail elsewhere (IMBP, 2010; ESA, 2011). A 520-day study was executed in the NEK-complex of the IBMP in Moscow 2009-2011) to simulate a time-realistic flight to the Mars and back. A 105-study preceded the 520-day study for methodological reasons. In each study, six international crew members took part. The experiment “6df” was ethically approved by the local committee in Germany.

II.I. Subjects

Six of the total twelve male Mars500 subjects (7 Russians, 4 Europeans, 1 Chinese) were untrained in docking maneuvers. Prior to the study, they had only been instructed on how to handle the software and hardware of the training device. The 6df-group was named “PILOT-2” group during the study. The group, which received intense docking training prior the study serves as the reference group “PILOT-1”. All subjects signed an informed consent prior the study.

II.II. Protocol

In both studies training sessions were performed from the beginning every 2 to 3 weeks. In the 105-day phase, subjects changed to the Russian standard docking training after 9 to 10 sessions of 6df (two weeks prior the end of the isolation phase). During the 520-phase, subjects switched the program after only 6-7 sessions (in the fourth month). The subjects took the decision, to finish the 6df-education and to start the standard docking training on their own.

II.III. Learn program “6df”

To apply, test and verify a training task for a broad normal population, a representative validation of the task type has to comply with general test criteria (Lienert, 1969). The task has to be stylized and abstracted from the space problem and applicable to subjects of different genders, ages or cultures. The task has to be unknown or at least untrained to the subjects. Each level of complexity or difficulty has to be adjustable from very easy (for each subject) to over-challenging. Additionally, an adaptive performance assessment tool should be implemented. The task type developed for the presented project and described below suffices all of these requirements. Additionally for the special application in space the functionalities of control, dynamics and calculated results have to be equivalent to the realistic models of the Spacecraft Docking.

The learning program was intended to simulate a virtual spherical object (”ELYPTOID”) controlled via a cockpit display with a Visual Adjustment Net (VAN). An object has to be navigated along a given and visible pathway. The paths are visualized by a series of ellipsoid rings, which have to be traversed with the object. Elliptic forms require turns around the object’s own axes. A pathway of ellipsoids that guide the spacecraft from its own position to the docking terminal of the station was displayed to prevent the spacecraft from deviating too far outside the approach sector.

The left hand control is used to move the object along the object axes x, y and z through the space and controls three axes of freedom (see figure 1). The technical term is "translation". In the Russian version the left hand control is a complex of switches which control relays which turn rocket engines on or off. The acceleration depends on the time when the engines are switched on. The synchronous control of two axes results in an orthogonal vector move. Two axes [y: down(+)-up(-), z: left(+)-right(-)] of the left hand control can be turned synchronous within ±15°. The x-axis it controlled by two switches "Forward"(-) and "Backward"(+).

The right hand control controls the turns of the object itself around the object axes x, y and z. The technical term is "orientation". Using the right hand control the object can be turned around the x-axis (bank) clockwise (-) and counterclockwise (+), around the y-axis (yaw) right (-) and left (+) and around the z-axis (pitch) down (+) and up (-). The acceleration of the turns depends on the analogue deviation of the hand control from the center and zero bank. Both hand controls are spring loaded and self-centering.

There are three main skill components to develop. The trainee has first to become able to anticipate the optimal path way towards the goal (3d-imagination), second to adequately perceive the relevant parameters flight direction, speed, distance to the station and third to control the free flying object with 6df along the anticipated path with an adequate speed in a more or less "automated" style.

The learning program started with single task elements while controlling only one hand control with one degree of freedom and watching the effects on the screen. This was followed by a combination of a few more elements to train the vector thinking as required for curve flights. The docking itself was trained in a later phase, emphasizing the perception of approach speed. Afterwards "complete" flights were trained. Instructions were extendedly given in a textbook and in a short form displayed on the screen for each task.

Six different sessions were prepared. They differed with respect to the sequence and the level of difficulty of the tasks. The subjects were instructed to repeat a respective session on their own discretion. Due to technical restrictions of the prototype software, the visual effects on the screen were the only feedback to the subjects.

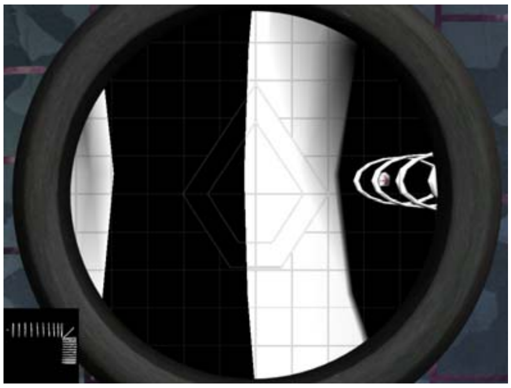

Figure 2) Screenshot „6df"

II.IV. Measurements

As a measure of individual training success, a final application of the Russian standard trainer for spacecraft docking was used in the last session of the isolation period and in the post-isolation session. The performance of the operators was assessed by using 302 measures of distances, velocities, accelerations, angle diversions, and angle velocities along different axes as well as fuel consumption of the spacecraft. Integrated performance parameters were provided for several flight phases of a re-docking maneuver. Finally, there was one common coefficient of accuracy calculated, which was be used in our analysis of the learn program efficiency.

For the standard docking training (Pilot-1) physiological parameter were registered to assess the actual load (physiological costs). They were neither registered during the 6df training nor for the 6df-group (Pilot-2) during their real docking training. Therefore, they will not be described in this paper.

III. RESULTS

Both studies are presented separately. During the 105-days study two of the three Pilot-2 (6df) subjects performed successfully the manual control of the Russian real docking training. The third participant failed due to excessive docking speed, however, he met the other coordination criteria. Interestingly, the three participants in the 6df-training experiment demonstrated comparable performance scores to the other three participants (figure 3) who had successfully completed training prior to the study. However, the low statistical power did not allow statistical significance testing.

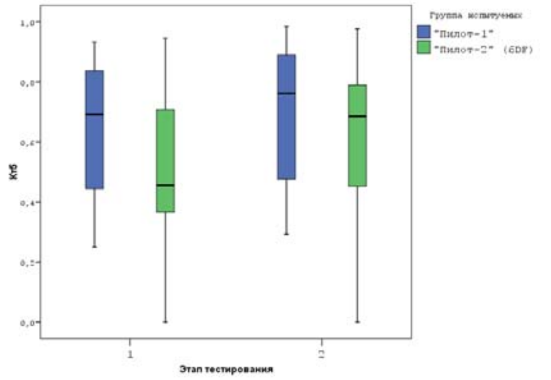

Figure 3) Mean coefficients of docking preciseness during the last session under isolation (1) and the first post-measure (2) of the 105-day phase. No differences are apparent between the docking trained group (left, PILOT-1) and the "6df"-Group (right, PILOT-2)

In the 520-day study, more data could be compared between both groups due to the length of the study and the early switch of the 6df-group (Pilot-2) to the "real" trainer. When summarizing the results for this report, the study was still ongoing. However, the most important results had been already obtained. Figure 4 presents the group means of the single task results. The PILOT-2 group seems to have a lower performance quality.

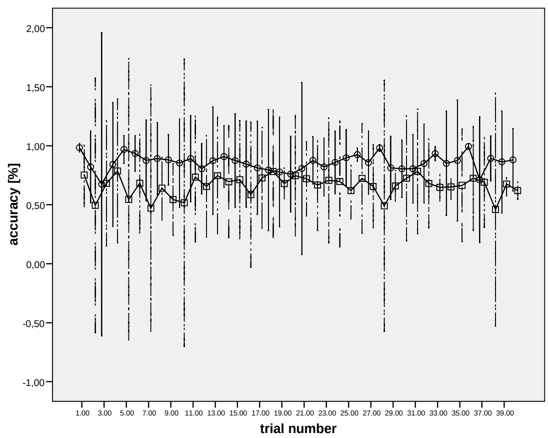

Figure 4) Group means (circles: Pilot-1, squares: Pilot-2/6df-group) of the docking preciseness for all docking tasks from October 2011 until March 2011 during the 520-day study.

Due to the small number of subjects a statistical comparison is impossible but the data of the 6df-group (PILOT-2) can be analyzed individually. Figure 5 clearly indicates that one of the subjects fulfilled the quality criterion of a successful docking stable over time. A second subject only sometimes met the quality requirements and the third subject had serious difficulties with the task.

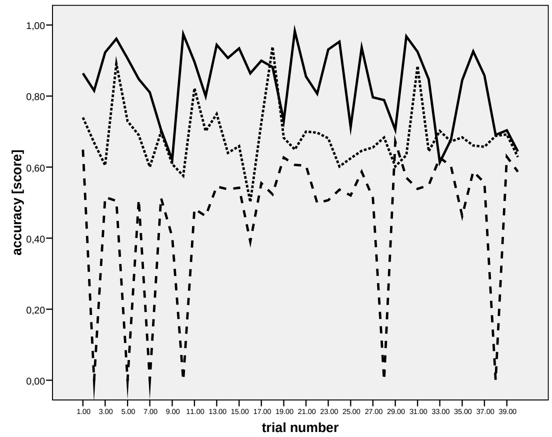

Figure 5) Individual results of the 6df-group in real docking quality after passing the learn program during the 520-day study.

Comparing the results between the 105-day phase and the 520-day study, one can assume a general higher performance level in both PILOT-groups during the 520-day study.

IV. DISCUSSION

Even in a prototype version, the visual feedback based training tool 6df provided promising results. There are clearly individual differences in the learning progress. For some subjects, possible "group pressure" lead to an too early switch to the real docking training. However, based on these generally successful results, a further development of the 6df has been granted by the DLR Space Agency. It is planned to improve the internal quality evaluation in the 6df program. As feedback, the flown track will be displayed to the subjects. The critical parts of the task will be repeated in variation of starting positions until the performance data stabilize. The "speed" of learning defines the increase of difficulty for the next task level and will vary between subjects. Also different learn styles may be relevant (learning from complete or partial feedback). This allows the provision of individual training programs for refreshment renewal and maintenance of the required skills. Trainings procedures will be designed and evaluated in separate studies in cooperation with university research (D. Manzey, TU Berlin).

In a second step it is planned to develop methods for the adaptation of the learning lessons based on objective evaluations of the actual performance as well as the registration of the actual psycho-physiological load. The learning course will be controlled individually by criteria, which ensure the required reliability of a certain sub-skill which is needed before entering the next higher level of complexity. The procedure also provides the identification of "weak" elements of already established skills which have uncertain reliability for the refreshment and maintenance training.

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