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Aptitude and Performance Testing for Manual Robotics and Docking Skills

Executive Summary

CONTRACTOR: **European Space Agency**

NLR – Netherlands Aerospace Centre

The picture on the cover shows the Soyuz TMA-03M docking with MRM-1 Rassvet in Earth orbit, bringing three crewmembers to the International Space Station in December 2011.

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AUTHOR:

H. van Dijk Netherlands Aerospace Centre

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Executive Summary

Problem Area

The main objective of the Aptitude and Performance Testing (APT) project was to develop an effective and efficient aptitude test battery for manual docking and robotics skills. An aptitude test battery with a high predictive value for future ATP skills that requires little resources would increase the effectiveness of ESA's training.

Description of Work

SOTA of Aptitude Testing

A review and documentation of the State Of The Art (SOTA) research was provided (in TN1) of aptitude testing related and relevant to the context of manual robotics and docking skills.

A total of 33 aptitude tests were reported. These tests were to serve as a reference base to create a test battery that can be used to measure and capture the skills needed for astronauts to excel on manual robotics and docking.

Analysis of Job Tasks and Definition of Predictive Performance Variables

Through a job analysis (and a detailed task analysis) and the results of the SOTA report a set of predictive performance variables applicable to aptitude testing for manual robotics and docking skills was identified. The manual robotics and docking tasks were analysed to identify the required skills and performance criteria of astronauts as well as the complicating conditions under which the tasks are performed.

Figure 1: Robotic workstation on board of International Space Station (ISS)

Figure 2: Soyuz control

To define the predictive performance variables, through the identification of competencies in the task analyses a questionnaire was created where the ESA instructors scored the relevance, difficulty to acquire, and difficulty to perform for each competency. The scorings provided a ranked-order list of candidates for the predictive performance indicators.

The competencies with the highest ranking were:

- Multitasking: Simultaneously operate two hand controls;
- Visualise a of manoeuvre before performing it (create a mental image);
- Decide to initiate a collision avoidance manoeuvre at certain distance;
- Estimate speed and distance when approaching ISS during docking;
- Multitasking: Simultaneously perform tasks and handle communication;
- Procedural knowledge (how to do things);
- Perceive misalignments during final approach;
- Workload management.

APT Battery Definition

The definition and design of the aptitude test battery was performed. The starting point was the 33 reported aptitude tests. However, this exceeds the number of tests that are realistic to use in a test battery. Therefore, it was considered necessary to reduce the number of tests by selection of the most relevant tests.

The following criteria for test selection were applied:

- That the tests reflect the most relevant abilities for manual robotics and docking identified in the task analyses;
- That the tests relate to abilities assessed as most relevant for manual robotics and docking, according to theoretical knowledge and empirical experience;
- That the tests are applicable in the validation study – mainly that a selected test does not take too long time to answer, that special competence is not required to administer the test, that it is not too complicated to administer the test, and that the test is available or can be implemented relatively easily.

Fifteen tests were proposed to be included in the aptitude test battery. Four of the tests in the proposed test battery were assessed as suitable for implementation in the Simulation Environment Prototype (SEP). These tests measure the following competencies: judgement of distance in 3D space, judgement or handling of view from different perspectives, task interference of motor skills, and tracking with different order of control.

Requirements for Simulation Environment Prototype for Manual Robotics and Docking Skills

Requirements for the SEP were provided. The purpose of the SEP is to generate a simulation environment in which tasks can be performed and tested that reflect key abilities for manual robotics and docking.

Three tasks were proposed to be performed in a 3D environment to reflect different aspects of abilities for manual docking and robotics: a planning task, a task where object move stepwise, and a task where objects move continuously. For all three tasks, manipulations that increase task difficulty were suggested.

Aptitude Performance Test Battery Validation Procedure

The validation procedure for the APT was designed. The purpose of the validation was to determine the performance prediction capability of the aptitude test battery.

Three different validation methods were proposed: two based on use of novices and one on use of astronauts. Of the two methods with novices one builds on on-site testing and the other on on-line testing. On-site validation means that the participants perform the test at a facility, while on-line validation means that the test is primarily performed using the internet.

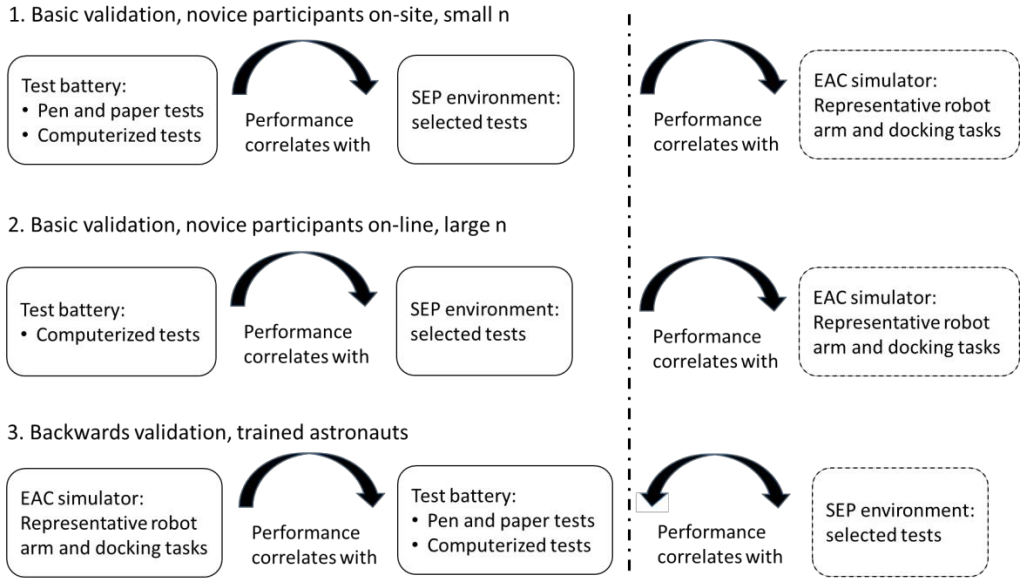

Figure 3: Overview of possible validation processes

Of the three proposed validation procedures firstly validation with astronauts was recommended, secondly on-site validation with novices, and lastly on-line validation with novice participants. Note that this recommendation is for an ideal validation study. However, in the context of the present project, practical limitations with each alternative had to be considered.

Skill Subset Rationale for Manual Robotics and Docking

A subset of cognitive and psychomotor skills to be used within the SEP simulation scenario was selected. In an expert meeting with subject matter experts, a subset of cognitive and psychomotor skills to be used in the SEP simulation scenario was selected.

The selection of cognitive and psychomotor skills to be used within the SEP simulation scenario resulted in the following subset of skills:

- Use of different frame of references;
- Planning of movements in six Degrees Of Freedom (DOF);
- Spatial memory of the structure of the station;
- Multitasking: Simultaneously operate two hand controllers;
- Estimate speed and distance;
- Perceive misalignments during final approach.

Description of Simulation Scenarios, Associated Test Battery Subset and Applicable Validation Procedures

Definition and development of simulation scenario

The subset of skills formed the basis for the development of the scenarios in the SEP. Although a specific scenario was developed for the 'spatial memory of the structure of the station', it was left out of the final challenges that were published online. After several design iterations, a group of nine students at ESA was asked to play the challenges and give their feedback. After this, the prototype was finalized using the feedback and prepared for publication in a final iteration.

Two SEP challenges were developed: a planning challenge and a control challenge.

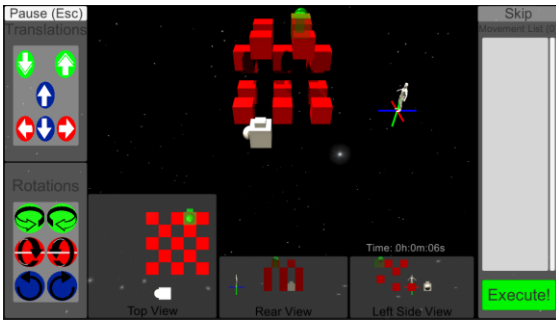

Figure 4: Screenshot of the planning challenge

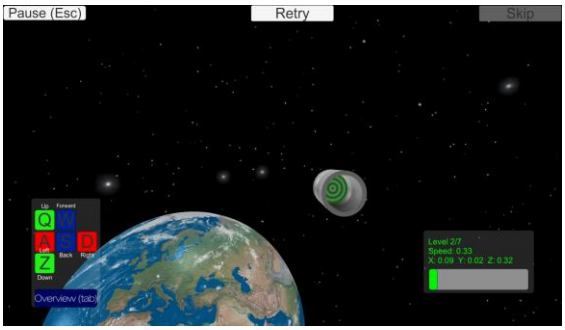

Figure 5: Screenshot of the control challenge

Applicable validation procedure

Three different validation procedures were proposed and discussed. In the context of the present project, the practical possibilities and limitations of each of these alternatives were considered and a choice was made on which the validation procedure was applied. This resulted in the proposal for the application of two validation procedures: (1) on-line validation with novice participants and (2) backwards validation with astronauts. Only the on-line validation procedure was performed.

The on-line validation with novice participants was conducted in three steps (the third step was not performed in the present study due to lack of availability of simulators, trainers and trainees):

1. A selection of tests from the test battery;
2. Computerization and integration of these tests in the SEP; and potentially;
3. Additional tests in the real manual robotics and docking simulators at EAC.

The selection of applicable tests from the proposed test battery was done based on basically three criteria: (1) availability of the test, (2) possibility to computerize the test, and (3) duration of the specific test. This resulted in the selection of two tests: the perspective taking test (testing spatial ability) and the Flanker inhibitory control and attention test (testing the abilities attention and vigilance). These two tests were computerized and integrated in the SEP environment and made accessible on-line. For the online experience, both tests were presented as the third and fourth challenge in the online environment.

Results and Conclusions

Validation Report

The APT validation results were presented. The purpose of this validation was to determine the performance prediction capability of the aptitude test battery.

In a period of 18 days 18.651 participants (novices) started the online test. From this group 1.183 participants completed the full test. After thorough data clean-up, a sample of 315 participants was used for statistical analyses.

The two SEP tests have been constructed as a more realistic and dynamic environment than standard test batteries. The advantage was that performances on the SEP tests required abilities that are more complex than standard test-items, but the drawback was that performances are not clearly indicative for specific, isolated abilities. The complexity also requires or enables a learning process, which further complicates interpretation of results.

The performance indicators for five of the six competencies have been addressed. For three competencies (‘planning of movements in six DOF ‘,’use of different frame of reference’, and ‘estimate distance’ (taken apart from ‘estimate speed’) the indicators appear to function. Validation however needs to be completed. Indicators for ‘multitasking’, ‘estimate speed’, and ‘perceive misalignment during final approach’ were not sufficiently strong in the current test set up. The lack of effects on these competencies was attributed to the test set up and not to issues with the indicators themselves.

Correlation analysis was used to investigate the relations between tests (or challenges). Correlations between the four tests on all metrics were considerably lower than expected and often non-existent. This was remarkable and there may be a technical cause for these findings. Note that this does not compromise the results of the SEP tests and the standardised tests as such.

Within the present study, the validation of the SEP tests could not be determined. First, astronaut data was not gathered. Second, the test-internal validation did not generate useable results. The tests that intended to assess similar aptitudes were expected to correlate. Correlations between the SEP environment (which elicits rather dynamic and complex behaviour) and the well-controlled, standardised tests (such as Flanker and the perspective taking test) may not be very strong, but a full absence of correlations of even moderate strength was not expected.

The test design was adequate enough to generate sufficient discriminative value for a novice group on both SEP tests, although several issues were found that may have weakened the test and the results.