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Human Reliability Test and Identification of HCR Model Basic Parameters for Single Factor "Meta-operation"

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The lack of basic data and the poor availability are a longstanding puzzle in human reliability analysis (HRA) of the manned space. In order to resolve this puzzle, we begin with analyzing task process operation to define "meta-operation", and then classify the process of tasks related to the single factor into seven kinds of "meta-operations" which cover both the rule type and skilled cognitive type. According to these seven kinds of "meta-operations", we design the test environments and the groups of experimental persons. Through five different groups of experimental persons, we obtain nearly 8000 valid experimental data. The analysis of these experimental data reveals that there is no significant difference among the different groups at the "meta-operational" level. From the analysis we also get seven kinds of human cognition reliability (HCR) model basic parameters. This work lays down a solid foundation for the next step research of the reliability of complex task personnel.

1. Introduction

As China becomes more deeply involved in manned spaceflight, the astronaut's reliability becomes of ever greater importance to the success of the mission, and is more and more widely attention. As this occurs, foreign and domestic scholars have focused a growing amount of research efforts in this direction. Yang(2012) researched into the overview of human reliability which has produced basic models to solve certain problems and assess complex manipulation task reliability, especially for "Meta-Operation". The work has laid a solid foundation for further study in the field of Human Reliability Analysis. However, due to the particular nature of different manned missions, data tends to be unreliable and limited. Solutions to the problems of Human Reliability Analysis must satisfactorily solve the problems arising from limited and unreliable sample data. This paper attempts to use the results of "Meta-Operating" analysis to identify a single factor for "Meta-Operation", and design appropriate testing environment for alternatives for reliability data accumulation, thus developing the ability to evaluate complex task operation reliability.

2. Single-Unit "Meta-Operations" Personnel Reliability Test

2.1 Primary Factors for Consideration

From personnel task classification, the complex task of personnel in the process of operation activities decomposed step by step according to the above classification method, and can reach the minimum operation action not to decompose combination, at the time the feeling and body movement of the influence factors for the least, so can define the personnel minimum operation action to be decomposed further as "Meta-Operation". Yang(2012) detailed analysis of personnel operating activities during manned spaceflight missions, known as "operations". From analysis of "meta-operations", operations are shown in table 1 below.

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Table 1: Schematic of Personnel Operations

categories	Upper limb movement	Lower limb movement	Upper and lower limbs coordinated action
Vision			
Hearing			
Smell			
Touch			

Using operational classifications, and combining related technical manual personnel operations of the specific content, we can determin the main type of operation and the main equipment. It can be seen that personnel operations involved the action of the upper limbs, in normal flight and emergency issues. So all type of single factor are involved in Table 1 can be simplified as Table 2.

Table 2 Personnel Operation Factor

Table size	Upper limbs	Non-limbs
Vision (the single factor)	Switch operations Link operations Taking and putting operations Writing operations	Meter type Indicator light type Appearance type

Judging by the significance of normal flight operations, it would appear most apparatus are visual in nature. Hearing and touch are primarily involved in movements of the upper extremities. Taking into account the complexity of the research work, the single factor experimental arrangement mainly consider the issues of personnel operating reliability under normal flight conditions.

So the main factor considered: 1) Instrument panel devices and connectors. 2) Test operations actions and upper-limb movements (switch operations, making connections, pick and place operations and fill operations), and visual observations (meter class interpretations, reading indicators and other observations).

2.2 Testing Equipment and Environmental Arrangements

Since test can not be conducted during equipment and environmental training in manned space missions, alternative methods must be used. According to the characteristics of the equipment analysis, and considering the time and financial constraints, this test is intended to be arranged in using virtual test instruments, instrument panels, displays, etc. The focus of the trial is to record information, interpret and take appropriate action. In this sense, the equipment type of panel operation test is similar with the space missions. In addition, the test selected two kinds of common connectors in the mission.

2.3 Testing Design and Implementation

Personnel of different types, different types of test participants, including lower grade undergraduate students, undergraduates, graduate students, doctoral students and laboratory technicians and five other groups were considered. Amongst each group of staff (three to five people), a person was selected to be responsible for the test organization and data recording, and testing process roles were alternated to obtain additional test data. Each group completed the testing on all equipment, and supplied 40 test samples each. Each group of staff therefore could produce between 100 and 200 data samples. This data can be used to facilitate the analysis of differences between the different groups. Approximately 500 to 1000 data samples on the current formulation of three to five devices is sufficient to support the extrapolation of a model that can meet the parameters with confidence. The five teams conducted the trial over a time-frame of about one and a half months. Prior to testing and collecting data, each group was made to understand the purpose and requirements of the testing equipment, and master their operations.

2.4 Test Data Collection

Data collection and management is the key to testing. The data was collected via filling-out data sheets during the test. Field data records are shown in table 3. Form arrangement involved 40 data fields per page, including device name, name of participating personnel, person responsible for recording data, test date, place, time to successful operation, etc. Data collected was for future comparison and analysis.

Table 3 – Test Data Collection Table

Test name		T—Connector				Test time			
Test device name		12 pins		Test group	A	Test place			
operator	register	operator	register	operator	register	operator	register	operator	register

Field data collection forms are then processed according to a prescribed format. They are checked for completeness, and then a preliminary analysis is conducted as data is entered into the computer to check for abnormalities. If necessary, abnormal data is removed.Tests are conducted in accordance with the testing arrangements considerations, and a total of eight scenes are performed and data recorded. The eight scenes are: T-head connection operation test, hole plug connect operation test, one-touch switch operation (touch type) test, key switch operation test, lift and place phone(from desktop to pocket) operation test, medical form operating test, indicator category judgment test, and instrumentation category judgment test. Each of the five teams was tested on each scene, and 200 operating data points from each test were collected. 1000 data points were collected in each scene in total. With eight tests in total, 8000 data points were collected. A thorough analysis of the data followed.

3. HCR Model Parameters and Identification Methods

3.1 HCR Model Parameters Identification Method

In order to carry out the personnel operating reliability analysis in complex task, we have already arranged the experiments of "Meta-Operation", and obtained a large amount of data. If these data can be used for predicting the personnel operating reliability in complex task, we must determine the each reliability of "Meta-Operation". According to the reliability model in the HRA, we considered HCR model has the standard expression form and clear meaning. Especially it could reflect the comprehensive effect of cognitive rules. So we selected HCR model as the basic paradigm of "Meta-Operation" reliability model.
Assuming the time to complete a "Meta-Operation" meets Weibull distribution, then

$$R(t)=\begin{cases}\exp\left\{-\left(\dfrac{t-\gamma}{\eta}\right)^{\beta}\right\} & t\geq\gamma\\ 0 & t<\gamma\end{cases} \tag{1}$$

Where $R(t)$ is the probability for completing a "Meta-Operation" at t. γ is location parameter, η is dimension parameter, β is shape parameter. Furthermore, we can get that

$$\ln\left[\ln\frac{1}{R(t)}\right]=\beta\ln(t-\gamma)-\beta\ln\eta \tag{2}$$

In order to reduce the inherent time differences, the operation time to completion is normalized. Standardized time is defined as $t/T_{0.5}$, where t is the operation completion time for the operator to complete a certain operation time. $T_{0.5}=\gamma+\eta\left(\ln 2\right)^{1/\beta}$ (3)

Using $T_{0.5}$ to normalize the processing operations time, we get:

$$R(t)=\begin{cases}\exp\left\{-\left(\dfrac{(t/T_{0.5})-C_{\gamma}}{C_{\eta}}\right)^{\beta}\right\} & t/T_{0.5}\geq C_{\gamma}\\ 0 & t/T_{0.5}<C_{\gamma}\end{cases} \tag{4}$$

Where $C_{\gamma}=\gamma/T_{0.5}, C_{\eta}=\eta/T_{0.5}$, β is constant.

Through the test, we can use fitting method to get estimated values of the above parameters. For the same set of test data in ascending order, $t_1,t_2,t_3,\cdots,t_N$, $R_i=\frac{i}{N+1}$ is the estimation of the operating task when t_i complete probability value. By the preceding definitions, we have:

$$\ln R\left(t\right)=-\left(\frac{t-\gamma}{\eta}\right)^{\beta} \tag{5}$$

$$\ln\left[\ln\frac{1}{R(t)}\right]=\beta\ln(t-\gamma)-\beta\ln\eta \tag{6}$$

According to the equation (2) and test data we can get the fitted values of β,η and γ by the method of least squares. Then, the fitted values of $T_{0.5}$, C_{γ} and C_{η} can be obtained.

3.2 Operation Test Data of HCR Model Parameter Identification

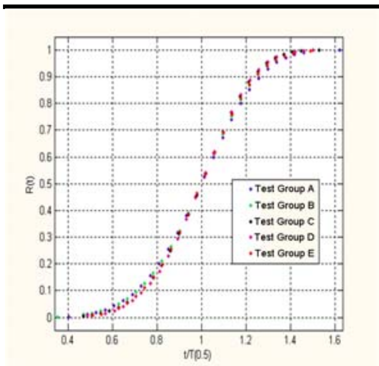
Tables 4 to 11 provide T head connection operation test, Hole plug connection operation test, single (contact type) switch operation test, a left key and a right key switch operation test, taking mobile phone (table to pocket), fill in the form and operation test, medical operation test, indicator lamps and visual judgment test, instrument visual judgment test, and HCR model parameter identification results.

Table 4: Test 1- T Head Connection Test Results

Test Group	γ	β	H	T0.5	Cγ	Cη
A	4	4.407	22.44257527	24.651301	0.162263	0.910401
B	1	5.284	25.77570156	25.048114	0.039923	1.029048
C	4	4.934	23.1847358	25.524616	0.156711	0.908328
D	6	4.521	20.20584926	24.632141	0.243584	0.820304
E	7	4.126	20.19291985	25.476238	0.274766	0.792618

Table 5: Test 2- Hole Connection Operation Test Results

Test Group	Γ	Β	H	T0.5	Cγ	Cη
A	7	3.829	18.7326689	24.022414	0.291395	0.7798
B	2	4.621	23.81485289	23.998628	0.083338	0.992342
C	8	3.49	17.37966526	23.646752	0.338313	0.734971
D	2	5.036	24.12097541	24.427541	0.081875	0.98745
E	5	4.379	21.08667327	24.393304	0.204974	0.864445



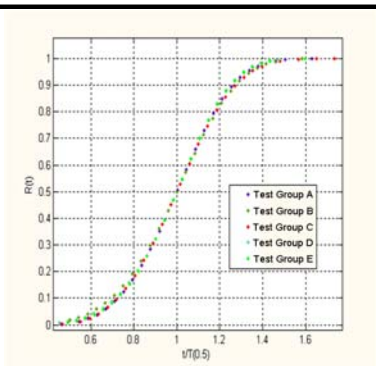


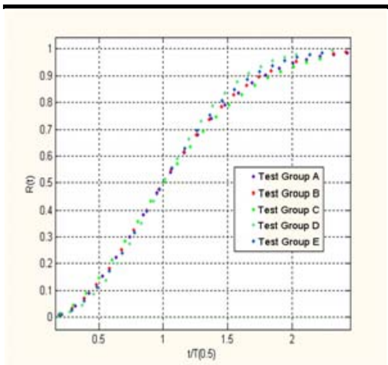
Figure 1: T Head Connection Test Results Plot   *Figure 2: Hole Connection Operation Test Results Plot*

Table 6: Test 3- Single Switch Test Results

Test Group	γ	Β	H	T0.5	Cγ	Cη
A	1	1.9105	10.2657637	9.4734475	0.105558	1.083635
B	1	1.9709	11.23913971	10.331591	0.096791	1.087842
C	1	1.8157	10.93983419	9.9398205	0.100605	1.100607
D	1	2.2761	11.54593747	10.828408	0.09235	1.066264
E	1	2.1017	11.07164045	10.299548	0.097092	1.074964

Table 7: Test 4- Left and Right Switch Operation Test Results

Test Group	γ	Β	η	T0.5	Cγ	Cη
A	1	2.6067	15.89046285	14.8058	0.067541	1.073259
B	1	2.6047	15.82672559	14.74894	0.067801	1.073075
C	1	3.2907	15.40007879	14.776628	0.067674	1.042192
D	1	2.2582	16.13118868	14.714056	0.067962	1.096311
E	1	2.6206	15.59346422	14.557874	0.068691	1.071136



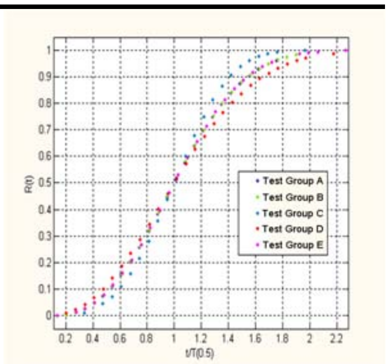


Figure 3: Single Switch Test Results Plot   *Figure 4: Left and Right Switch Operation Plot*

Table 8: Test 5- Taking Mobile Phone Operation Test Results

Test Group	γ	B	η	T0.5	Cγ	Cη
A	4	3.55	28.49871946	29.702722	0.134668	0.959465
B	1	3.9486	32.52449891	30.640907	0.032636	1.061473
C	1	4.4003	32.08536098	30.5207	0.032765	1.051266
D	3	3.821	30.75542725	30.941917	0.096956	0.993973
E	3	3.3768	42.02036853	40.697575	0.073714	1.032503

Table 9: Test 6- Filling-Out Medical Form Test Results

Test Group	γ	β	η	T0.5	Cγ	Cη
A	37	4.9173	45.24315233	78.992964	0.468396	0.572749
B	36	4.9364	45.80746025	78.528999	0.458429	0.583319
C	31	5.6887	53.0391483	80.729091	0.384	0.657002
D	18	6.9095	66.28316116	80.858191	0.222612	0.819746
E	37	5.255	47.60737236	81.39954	0.454548	0.58486

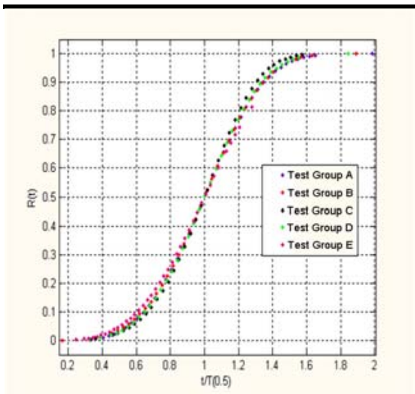


Figure 5: Taking Mobile Phone Operations Plot

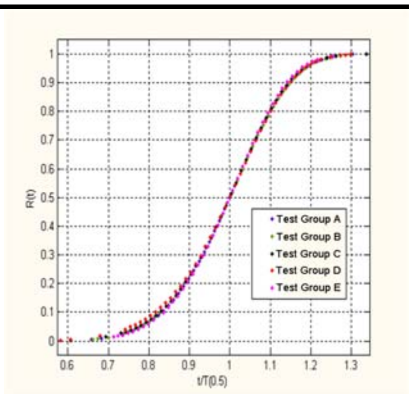


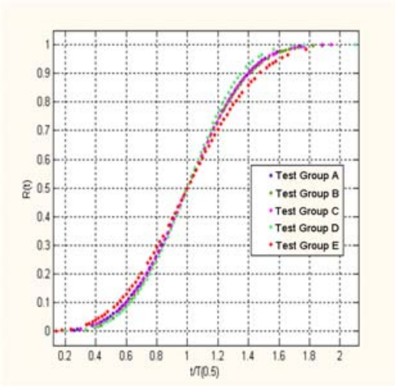
Figure 6: Filling Out Medical Form Plot

Table 10: Test 7- Indicating Lamps and Visual Judgment Test Results

Test Group	γ	β	η	T0.5	Cγ	Cη
A	1	3.5324	54.80565899	50.403274	0.01984	1.087343
B	9	2.9898	46.85604702	50.449239	0.178397	0.928776
C	2	3.4673	52.66184619	49.37838	0.040504	1.066496
D	1	3.927	54.30696059	50.466889	0.019815	1.076091
E	1	3.0465	55.30158531	50.031993	0.019987	1.105324

Table 11: Test 8- Instrument Visual Judgment Test Results

Test Group	Γ	β	η	T0.5	Cγ	Cη
A	18	4.0586	57.22334855	70.281364	0.256113	0.814204
B	10	4.2946	65.57275226	70.207785	0.142434	0.933981
C	3	5.2363	72.37350148	70.48009	0.042565	1.026864
D	7	5.388	68.29460235	70.802615	0.098866	0.964577
E	12	4.6821	61.81943304	69.16396	0.173501	0.89381



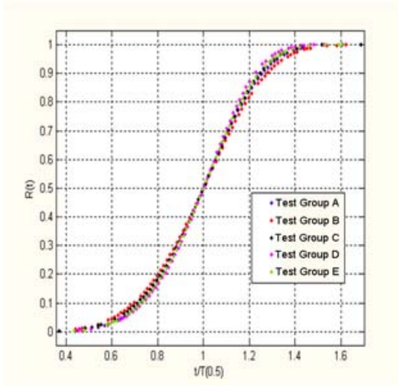


Figure 7: Indicating Lamps and Visual Judgment Plot   *Figure 8: Instrument Visual Judgment Plot*

Figures 1 to 8 reveal the estimated probability curve of tests 1 though 8. Grouping trends were similar according to probability estimation value curves. The analysis of the parameters identified in the table showed that individual areas also showed some differences, but the fundamental differences reflect the different team level, which remains as the next step in for detailed analysis.

4. Summary

Personnel operational reliability testing can look at many factors. This study is just a simple study attempting to put forward the basic method of operational reliability testing and parameter identification, given the eight categories of the test as well as test data. The results of parameter identification, experimental design and data processing method is scientific and reasonable. However, in a sense, the study's principal also can not fully support the study of the complex task of reliability assessment, as comparisons of task execution differences between personnel need further analysis, and further work will be required to expand this subject. Research work will evaluate the health management (PHM) system reliability of the astronauts operating instruments and equipment in space missions, and put forward improvement Suggestions for affecting the PHM station operating reliability problems.

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