Critical Personality Aspects for Human-Machine Interaction in highly automated Aviation

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***Abstract*—Working safely and successfully with highly automated human-machine interfaces of future aviation is not only a matter of cognitive performance, but also of personality. This study examines which personality aspects correlate with safety-critical performance in human-machine (hybrid) teams. Personality was surveyed with the Hybrid Team Questionnaire HTQ and the Balloon Analogue Risk Task BART which measures risk taking. The Hybrid Interaction Scenario HINT simulates relevant processes in future human-machine team interaction in aviation and was used as performance measure. In an exploratory study with 156 applicants for aviation careers, safety-critical effects of some facets of general personality as well as risk taking were found. Especially personality aspects concerning disinhibiting, spontaneous behaviour and sensation seeking show correlations with poorer performance in the HINT simulation.**

Keywords-Human-Machine Team; Hybrid Team; Automation; Aviation; Personality; Risk Taking

I. Introduction

Working procedures in aviation become more and more automated. The European air traffic management (ATM) modernisation programme SESAR (Single European Sky ATM Research) envisages the implementation of new automated functions in ATM. According to the SESAR Concept of Operation "humans (with appropriate skills and competences and duly authorised) will constitute the core of the future European ATM System's operations. However, […] an advanced level of automation will be required. […] The nature of human roles and tasks within the future system will necessarily change" [37]. The usual kind of collaboration between air traffic controllers (radar controller and coordinator) and pilots (pilot and co-pilot) is expected to decrease. Instead, the ability to work as the human part of a human-machine-interface will become increasingly important. The ability to automate ATM processes is limited and ATM will therefore continue to be a human centric process in which the responsibility and the authority for the negotiation will continue to rest on human controllers and pilots [9]. This generates a situation in which future working procedures have to be performed by a human and an automated system in close interaction.

The character of human-machine interaction changed over the past decades. The frequently quoted HABA-MABA-concept (humans are better at…/ machines are better at…) [15], described for example in [4], is nowadays contrasted with the wish to develop human-machine interaction to human-machine cooperation [18]. This paper takes up the terms „human-machine team“ [30] and “hybrid team“ [13] to characterise this close cooperation. Other terms used in the literature are, for example, „human-agent team“ [7] or „human-robot team“ [17].

Definitions of team work can also be applied to close human-machine cooperation. Generally, teams are characterised as social entities of members with high task interdependency and shared and valued common goals [8, 34]. However, the cooperation of humans and machines often includes these characteristics as well. Air traffic control provides an example: the technical air traffic control (ATC) systems are - among other things, of course - designed to maintain safety distances between aircraft. If the safety distance is undercut, the system indicates visual warnings that are processed into controller instructions to the pilot. This simple example shows that also this human-machine cooperation includes task interdependency (human and system are responsible for safety distances) and shared goals (human and system have the goal to maintain safety distances). First ideas on this topic have been considered by Hollnagel and Woods [19] which stated that “through the increasing sophistication of computer applications, the man-machine interface is gradually becoming the interaction of two cognitive systems.” Woods [38] developed this idea and stated that the implementation of automatic systems to support human operators basically means to integrate new team members. He explained that the design of new automated and computerised systems is more than hardware and software. It is also the design of a team of people and machines which has to coordinate its evaluations and activities as soon as a situation increases in tempo, difficulty and danger.

The need of human-machine teamwork in aviation can lead to a change of ability requirements of future personnel. Other research focused the performance part of ability requirements [5, 9]. Since personality is a relevant factor of eligibility for a job as well, this study in cooperation with DLH Deutsche Lufthansa AG and DFS Deutsche Flugsicherung GmbH addresses future requirements regarding the personality of operators. Because "although it may be difficult to anticipate how automation will affect a job, it is advantageous to anticipate job changes well in advance so that appropriate selection criteria can be identified and implemented in at the same time as operational versions of automated systems" [27].

The concept of personality, used for this study, stems from Gerrig and Zimbardo [16] and defines it as a complex set of psychological qualities which influence the characteristic behaviours of an individual in many situations, and for a longer period of time. Regarding the question of how these patterns are structured and categorised, there are various approaches that find their expression in different personality theories. These personality theories can be described as hypothetical statements about the structure and functioning of individual personalities. The various statements include, inter alia, predictions about how people react and adapt to certain conditions [16]. For this research, only personality aspects within the range of a healthy and normal adult personality were taken into account. Mental health problems or disorders, which are obviously safety-critical – recalling the Germanwings catastrophe in 2015 [2], for example – are not part of the study.

Up to now, the field of human-machine interaction offers little research that specifically deals with personality as an influencing factor. However, Kain and Nachtwei [22] worked on the role of control variables in human factors (HF) research and reviewed studies focusing the prediction of HF-relevant external criteria. They summarised a positive correlation between neuroticism and risky driving in a road traffic study, a positive correlation between conscientiousness and effort in a simulated ATC study and a negative correlation between risk seeking and situational awareness in a simulated aircraft piloting study.

Taking these results into account, the following hypotheses were formulated:

(1) There are aspects of normal adult personality that are critical to performance in human-machine teams.

(2) The trait risk taking is critical to performance in human-machine teams.

The hypotheses are deliberately kept fairly general to be open to any critical effect of personality on the performance in human-machine teams.

II. METHOD

Several consecutive steps and studies resulted in a final study concerning personality in human-machine teams, which will be described below. The necessary tools HTQ (Hybrid Team Questionnaire) and HINT (Hybrid Interaction Scenario) will be presented in their function. Their development is described in [10] and [24].

The reported study was part of the HYBRID project, funded by the German Ministry of Education and Research BMBF and the German Aerospace Center DLR with a German excellence cluster grant.

A. *Study Design*

The conducted study consisted of various elements including the NEO-PI-R (as first part of the HTQ), the Balloon Analogue Risk Task (BART) and HINT. Further elements of the study are subject of additional literature [11].

The duration of the study was around 3.5 hours per run. A maximum of four candidates could participate at the same time. The subjects were contacted during their selection processes for DFS or DLH and asked to participate in a study on the "requirements for future aviation operators". Participation was voluntary. For participation, subjects received between 50€ and 60€ as compensation. The investigations took place from March to November 2012 at the German Aerospace Centre DLR in Hamburg and were conducted by DLR test leaders. Fig. 1 shows the study setup.

B. *Sample*

All in all, N = 156 applicants executed the study, 101 of them being DFS candidates and 55 of them being DLH candidates. 27.6% of subjects were female. The average age of all subjects was 20.02 (SD = 2.08). Participation was more difficult to realise for DLH candidates as the structure of the DLH selection process contained less time slots for participation than the DFS selection process. This resulted in the different size of the DFS and DLH sub-samples. Additionally, there are different sample sizes available for different variables. All 156 subjects executed HINT, but due to a necessary software change in the simulation during the survey period, some of the HINT variables are only available for a reduced number of 69 participants. All other variables were collected for the full sample. However, there are missing values for two subjects in two variables. These subjects were included in the analyses where data were available.

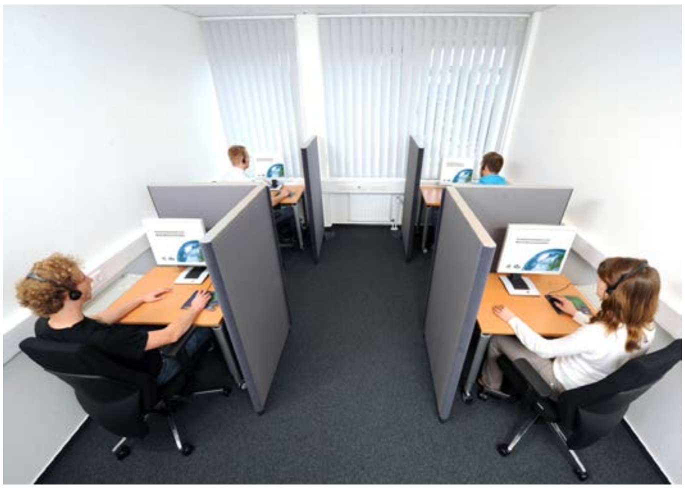

Figure 1. Study Setup, ©DLR

C. The Research Questionnaire HTQ

The Hybrid Team Questionnaire HTQ focuses on three aspects: general personality, teamwork and technology-related personality aspects. It is completed by variables on flexibility, self-efficacy and cognitive failures. All scales of the HTQ are answered on a five-point scale. In most cases the scale ranges from 'strongly disagree' to 'strongly agree'. Table 1 shows the HTQ scales with their authors.

A major part of the HTQ is the revised NEO Personality Inventory (NEO-PI-R [31]), to measure general personality. Due to its relevance for the current study it will be described in detail. Details regarding the additional scales can be found in [11].

NEO Personality Inventory – Revised Version

The German version of the revised NEO-PI-R is a 240-item measure of the Big Five personality traits and six subordinate dimensions (facets) of each. The personality dimensions including facets and one example item are listed below:

- Neuroticism (Anxiety, Hostility, Depression, Self-Consciousness, Impulsiveness, Vulnerability to Stress). Example: *Sometimes I feel completely worthless.*
- Extraversion (Warmth, Gregariousness, Assertiveness, Activity, Excitement Seeking, Positive Emotion). Example: *I am dominant, forceful, and assertive.*
- Openness to experience (Fantasy, Aesthetics, Feelings, Actions, Ideas, Values). Example: *I think it's interesting to learn and develop new hobbies.*
- Agreeableness (Trust, Straightforwardness, Altruism, Compliance, Modesty, Tender-Mindedness). Example: *I would rather cooperate with others than compete with them.*
- Conscientiousness (Competence, Order, Dutifulness, Achievement Striving, Self-Discipline, Deliberation). Example: *I try to perform all the tasks assigned to me conscientiously.*

TABLE I. HTQ SCALES IN ALPHABETICAL ORDER

Test Initial	Test Name	Source
BFI-10	Big-Five-Inventory-10	[32]
BIP	Bochum Inventory of job-related Personality	[21]
CFQ	Cognitive Failure Questionnaire	[26]
CNFB	Computer Usage Questionnaire	[35]
FIT	Individual Attitude towards Teamwork Questionnaire	[28]
INCOBI-R	Computer Literacy Inventory	[33]
KUT	Locus of Control when Interacting with Technology	[3]
NEO-PI-R	Revised NEO Personality Inventory, German Version	[31]
SWE	Generalised Self-Efficacy scale	[36]
TA-EG	Technology Affinity - Electronic Devices	[23]
CaP	Complacency as Potential	[14]
NfT	Need for Teamwork	[11]
AtA	Attitude towards Automation	[11]
BIO	Biographical Questionnaire	[11]

D. The Balloon Analogue Risk Task

The Balloon Analogue Risk Task (BART [25]) is a laboratory-based behavioural measure of risk taking. Participants are asked to pump a simulated balloon on the computer screen by pressing on a button labelled "pump" which is also displayed on the screen. With each pump, the balloon increases in size and can eventually explode if pumped too much. The participants are given no information about when the balloon will explode. The explosion of the balloon occurs at varying counts of pumps. Participants receive points with each pump which are stored in a temporary bank. Next to the "pump" button, a button labelled "collect" is displayed. By pressing the "collect" button, participants can transfer the points in the temporary bank to their permanent bank of points. After collecting the points, a new balloon appears and a new trial starts. If, however, the balloon explodes before participants collect the points from the temporary bank, they are lost and the next balloon trial starts.

Altogether, 30 balloon trials were conducted in the present study. The balloons were set to explode after a variable amount of pumps (on average 54 responses). Scoring for the BART included the total count of pumps, the total amount of points won, and the frequency of popped balloons. Higher risk taking should lead to a higher number of popped balloons and a higher count of total pumps. The total amount of points won should display a rather reversed u-shaped relationship with risk taking – that is, some risk taking would be beneficial as more points are gained. However, with decision making becoming too risky, the losses due to popped balloons overweigh the gains from a high amount of pumps and thereby more points are lost than won. Fig. 2 shows the execution of the BART.

Figure 2. Execution of the Balloon Analogue Risk Task, ©DLR

E. The Hybrid Interaction Scenario

The Hybrid Interaction Scenario HINT was conceptualised based on the anticipation of hybrid teamwork. It simulates relevant aspects of future interaction between a human operator and an automated system in aviation. Although forecasting the future is always associated with uncertainty, HINT can be used to assess the central requirements of future operators such as system monitoring or 'operational monitoring' [9], reaction to unexpected incidents, and the interaction of an operator with an automated operation assistance system via input devices. HINT simulates a simplified air traffic environment in two separate but connected sectors. Each sector is controlled by one operator, the participant being one of them (Alpha) and an automated system (Beta) taking charge of the second sector. Each sector contains an inbound area from which aircraft enter the sector and an outbound area from which aircraft leave the sector. Two routes connect the inbound and outbound area in each sector that can only be used one-way (i.e. from inbound to outbound). Fig. 3 depicts a screenshot of the HINT simulation with traffic. For each sector, target values of aircraft are assigned to both the inbound and outbound areas, and routes between these areas. For example, a target value of 2 on a route implies that 2 aircraft should be using the route at the same time.

Participants were asked to manage the incoming and outgoing traffic such that all target values are met to the best possible degree. They were also instructed to monitor their partner sector which is managed by the automated operation system to ensure that the target values are met in both sectors. In order to achieve an overall fit of target values, aircraft could be exchanged between the inbound and outbound areas of the sectors. By making requests (RQ), participants could gain additional aircraft in their inbound area and give away aircraft from their outbound area. These aircraft then were subtracted from or added to the correspondent area of the partner sector. Vice versa, the automated operation system could also request aircraft from the sector managed by the participant. However, all requests by the automated operation system were beneficial to the reduction of the difference between target and actual value of aircraft either in the inbound or outbound area. Additionally to managing the air traffic and trying to achieve the target values, participants had to monitor for 'critical' aircraft (CAC). These were aircraft that have left their planned flight trajectories and needed to adapt speed or altitude. This adaptation could be achieved by the operator via an input area (Fig. 3, upper right).

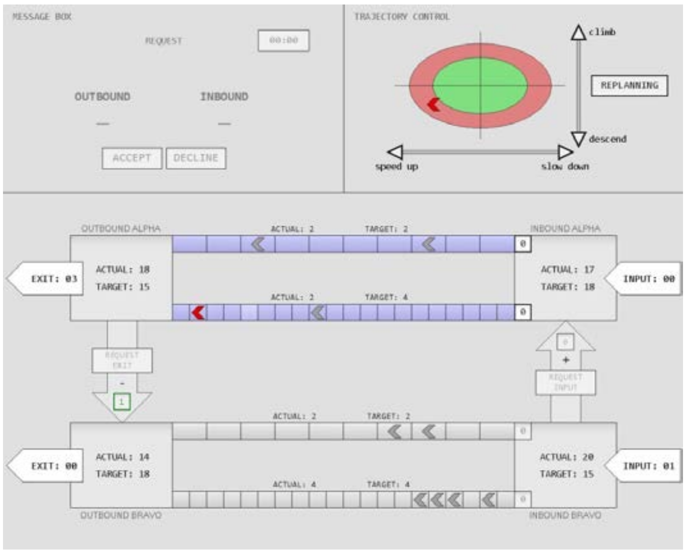

Figure 3. Screenshot of the HINT Simulation, ©DLR

HINT generated a wealth of data points. Every two seconds the actual state of 12 performance parameters was recorded. In a first step, mean values of the performance parameters concerning the total processing time were calculated. These were further grouped in a second step, based on considerations of their content, so that finally seven variables with informative value in terms of the performance and behaviour of the human operator Alpha were available. Detailed analyses concerning the composition of the performance variables had been conducted beforehand. The resulting variables are described in Table 2. If different origin variables were combined into one variable, these were z-standardised prior to being summarised.

TABLE II. HINT-VARIABLES AND THEIR MEANING

Variable	***Meaning***	***Polarisation***
Correct Critical Aircraft (CAC) Handling	Relative amount of correctly handled CAC	high values = many correctly handled CAC
Reaction time	Mean time until a CAC is activated and correctly handled, as well as relative amount of CAC not handled	high values = slow reaction time
Requests of Alpha to Bravo	Amount of requests from Alpha to Bravo	high values = large amount of requests
Request Rejection by Alpha	Relative amount of requests rejected by Alpha	high values = large amount of rejected requests
Request Acceptance by Alpha	Relative amount of requests accepted by Alpha	high values = large amount of accepted requests
Target Deviation Alpha	Mean deviation from all target values in the inbound and outbound area as well as on the routes of Alpha	high values = high deviations
Target Deviation Bravo	Mean deviation from all target values in the inbound and outbound area of Bravo (only these can be influenced by Alpha via requests)	high values = high deviations

Note: The request variables are indicators for the willingness of the subjects to work with their automated partners, i.e. for cooperative performance.

F. Data Analysis

All statistical analyses were conducted with the software SPSS™. As the sample of the study is highly selective, all variables were checked for normal distribution and sufficient variance before being further analysed. To determine the correlations between the HTQ scales and the HINT simulation, Pearson correlations were calculated. Additionally, partial correlations concerning gender effects were executed. Further analyses of the HTQ as well as detailed item analyses can be found in [11].

III. Results

The variable checks for normal distribution and sufficient variance revealed that further analyses are possible. Histograms for all variables are available in [11]. The means and standard deviations of the HTQ variables are available in [12]. The values of the NEO-PI-R variables were additionally compared with the NEO-PI-R values of 11.724 subjects of the norm sample of the German NEO-PI-R [31] to screen for apparent differences. This visual inspection revealed similar values. However, the majority of the standard deviations in the current study tend to be slightly lower compared to the norm sample, indicating a smaller variance.

Concerning the HINT measures, the variable CAC Handling showed to be dispensable for further analyses, because of a lack of variance. Due to a ceiling effect of the CAC task, apart from 13 participants all other 143 participants obtained the optimal test value. The variable is therefore left out for all following analyses. However, the mean time until a CAC is activated and correctly handled, as well as the relative amount of CAC not handled, both summarised in the variable Reaction Time provide valuable information concerning the quality of CAC handling.

Table 3 shows an overview of Pearson correlations between HTQ and HINT variables. For the sake of clarity, here, only the significant correlations relevant for the question of safety-criticalness are included. Further results have been previously discussed in [11]. As Significant correlations of HTQ and HINT reveals, Openness of the Big-Five-Inventory-10 as well as facets of Neuroticism, Extraversion, Openness and Agreeableness show significant correlations to HINT variables in a safety-critical direction.

To reveal possible gender effects, partial correlations for all variables showing a significant correlation with HINT variables as well as gender were executed. Table 4 includes the results. It shows that the correlations between the HINT variable Reaction Time and the variables Openness and Tender-Mindedness are no longer significant (n.s.) after partialling out gender. However, two correlations have also been concealed before. Vulnerability also correlates with the acceptance of requests by alpha and Impulsiveness correlates with reaction time.

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TABLE III. Significant correlations of HTQ and HINT

HTQ-Variables	**HINT Variables**					
	Reaction Time	***RQ of Alpha to Bravo***	***RQ-Rejection by Alpha***	***RQ-Acceptance by Alpha***	***Target Deviation Alpha***	***Target Deviation Bravo***
NEO-PI-R: Vulnerability (Neuroticism)	.19*			-.16*		
NEO-PI-R: Excitement Seeking (Extraversion)					.25*	.28*
BFI: Openness	.19*					
NEO-PI-R: Openness to Actions (Openness)					.24*	
NEO-PI-R: Tender-Mindedness (Agreeableness)	.18*					
	N=154	*N=69*	*N=154*	*N=154*	*N=69*	*N=69*

Note: * p < .05 (two-tailed)

TABLE IV. Partial Correlations for Variables with Significant Correlations with HINT Variables and Gender

HTQ-Variables	**Gender Effects**		
	Correlation with Gender	***Correlation(s) with HINT-Variable(s)***	***Partial Correlation(s) without Gender***
NEO-PI-R: Vulnerability (Neuroticism)	.18*	.19* (Reaction Time) n.s. (RQ-Acc.by Alpha)	.16* -.17*
NEO-PI-R: Impulsiveness (Extraversion)	.27**	n.s. (Reaction Time)	.16*
BFI: Openness	.27**	.19* (Reaction Time)	n.s.
NEO-PI-R: Tender-Mindedness (Agreeableness)	.21**	.18* (Reaction Time)	n.s.

Note: * p < .05 (two-tailed), ** p < .01 (two-tailed), N =156

The analyses reveal that participants with higher values in Vulnerability show the tendency to react slower (positive correlation with reaction time) and accept less requests of the automation (negative correlation with RQ-Acceptance by Alpha) than less vulnerable participants. The facet Excitement Seeking correlates with three of the performance variables of HINT. Participants with a stronger desire to seek excitement act slower (positive correlation with Reaction Time) and achieve larger target deviations in their own sector Alpha and the automated sector Beta (positive correlations with the deviation variables). The facet Openness to Actions is linked with higher target-deviations in the own sector Alpha. The positive correlation between Impulsiveness and Reaction Time shows that more impulsive participants act slower in the simulation than less impulsive ones.

Table 5 includes the Pearson correlations of the variable risk taking, measured by the BART. It shows that a higher tendency towards risk taking correlates with higher target-deviations in the Alpha sector. Thus, participants with a lower tendency towards risk taking work more rule-consistent, as they minimise the discrepancy between target and actual values. Concerning the other HINT variables no significant correlations could be found.

TABLE V. SIGNIFICANT CORRELATIONS OF THE BALLOON ANALOGUE RISK TASK AND HINT

HTQ-Variables	HINT Variables					
	Reaction Time	*RQ of Alpha to Bravo*	*RQ-Rejection by Alpha*	*RQ-Acceptance by Alpha*	*Target Deviation Alpha*	*Target Deviation Bravo*
Risk Taking					.27*	
	N=154	*N=69*	*N=154*	*N=154*	*N=69*	*N=69*

Note: * p < .05 (two-tailed)

IV. DISCUSSION

The significant correlations between personality and HINT measures range from .16 to .28. This corresponds to other studies concerning the relation between personality and performance, which usually identify small to medium effects [11]. However, the results of this exploratory study have to be interpreted with caution. Regarding the characteristics of null hypothesis significance testing the found correlations could also be significant by chance, as a large number of correlations have been analysed. Nevertheless, the results are in line with the findings of Kain and Nachtwei [22] who reported relationships between aspects of the Big Five as well as risk seeking with performance related variables and are therefore further explored in the following.

As described before, participants with higher values in Vulnerability, a facet of the Big Five factor Neuroticism, show the tendency to react slower and accept less requests of the automation than less vulnerable participants. The directions of the correlations both are an indicator of poor HINT performance. Vulnerability is defined as a general susceptibility to stress which conforms to the mentioned correlations with a slow reaction time and poorer request handling. The impacted performance can be understood as a negative response to the stress induced by working with HINT. These findings support earlier studies that also found a negative influence of Neuroticism on work performance (Barrick, Mount, & Judge, 2001). However, concerning HINT only the facet Vulnerability showed a correlation and not Neuroticism as a whole factor.

The facet Openness to Actions, a facet of the Big Five factor Openness, is linked with higher target-deviations in the own sector Alpha, i.e. poorer performance, as described above. According to [1] Openness does not predict overall work performance but can predict success in specific occupations or relate to specific criteria. As mentioned before, the correlation to poorer performance in this study is shown for the facet Openness to Actions. According to the definition of this facet as openness to new experiences on a practical level [6] an overlap of this construct with excitement seeking, which is defined as the need for environmental stimulation and belongs to the Big Five factor of Extraversion, can be assumed. This can be an explanation for its negative impact on target-deviations. The latter also has a negative impact on HINT performance. As mentioned before, participants with a stronger desire to seek excitement acted slower and achieved larger target deviations in their own sector Alpha and the automated sector Beta. At first sight this result contradicts previous findings indicating that Extraversion has a positive impact on work performance. However, this positive impact has been found to be related to job performance in occupations where interactions with others are a significant proportion of the job [29]. Being less extraverted might be quite positive for the cooperation with an automated system instead of a human team partner. Additionally, it seems preferable for safety-critical jobs like ATCO or pilot to work with individuals not being too adventurous, daring and risk seeking which are all characteristics of the facet Excitement Seeking.

The positive correlation between Impulsiveness and Reaction Time shows that more impulsive participants act slower in the simulation than less impulsive ones. This facet, also belonging to Neuroticism, can be defined as the tendency to act on cravings and urges rather than reining them and delaying gratification. Although Neuroticism is generally correlated with poorer job performance (see above), the positive correlation with Reaction Time in particular seems unexpected. A correlation in the other direction with a reduced Reaction Time for impulsive (and therefore normally fast reacting) participants would rather be expected. However, a closer look at the variable provides clarification. Here, not only the mean time until a CAC is activated and correctly handled, but also the relative amount of CAC not handled are summarised in one variable. One explanation for the Impulsiveness result could be that participants with higher values handled less CAC due to their tendency to act on cravings and urges. Working on the main HINT task, the flow management of the incoming and outgoing aircraft, the handling of CAC might have been perceived as an annoying disturbance for impulsive characters that had to be ignored to be able to work on the main task which was observed as the main urge.

The results concerning risk taking, again, are in line with the findings of Kain and Nachtwei [22]. In their study they report a negative impact of risk seeking on situational awareness. In the current study a higher tendency towards risk taking correlates with higher target-deviations in the Alpha sector. Thus, participants with a lower tendency in this variable work more rule-consistent, as they minimise the discrepancy between target and actual values. Possible is also a less careful, i.e. more risky, monitoring behaviour that leads to higher deviations.

It is noteworthy that the personality aspects concerning disinhibiting, spontaneous behaviour and sensation seeking show correlations with poorer performance in the HINT simulation. Vulnerability, Impulsiveness, Openness to Actions, Excitement Seeking, and Risk Taking are all having a safety-critical impact on the performance in HINT (see Critical Personality Aspects).

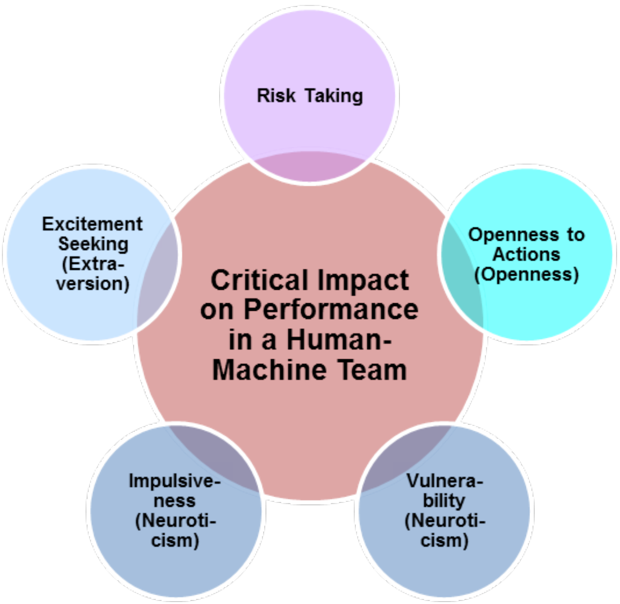

Figure 4. Critical Personality Aspects for Human-Machine Teams

V. CONCLUSION

The formulated hypotheses of this study are supported by the results. Both, aspects of normal adult personality and risk taking are safety-critical to performance in human-machine teams. Especially personality aspects concerning disinhibiting, spontaneous behaviour and sensation seeking show correlations with poorer performance in the HINT simulation. However, the limitations of the study have to be taken into account – a highly selective sample and only a few significant correlations. Nevertheless, the results of the study are a good first step to explore personality's impact on human-machine teams. Further research with different samples is necessary to substantiate the results.

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