Just talk - An experimental task for investigation of Team Situation Awareness

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Abstract

Background: In highly dynamic and complex work environments teamwork is omnipresent and it is crucial for performance that team members have a high degree of individual as well as team situation awareness (TSA). Method: The paper reviews approaches for measurement of the TSA. Next, an approach for empirical investigation of the development of team situation awareness by means of communication analysis is presented. The main objective of the approach is to provide an experimental environment that allows for a high degree of experimental control as well as sufficient task complexity. Thus, TSA is a substantial factor for team task performance. In a first step, individual communication behaviour and the influence of personal traits is examined. Results: The approach is applied to a single-person conflict detection task, where participants have to ask for information in order to detect conflicts. First empirical results of N = 16 participants indicate, that individuals have different communication behaviours within the task. Furthermore, by means of cluster analysis, three distinct behaviours could be identified. Outlook: The approach will be tested in a team task with two interacting participants. Results of the conflict detection task will be used to control the set-up of the teams.

Introduction

In aviation research, the construct of situation awareness has been defined as ‘the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future’ (Endsley, 1988, p. 97). Generally, in highly dynamic and complex working environments, like safety critical domains, operators (e.g. air traffic controllers or surgeons) have to maintain a sufficient level of situations awareness by constantly updating their mental picture of the situation. Additionally, in complex working domains several operators have to coordinate their work with a high degree of task interdependency. Thus, besides individual situation awareness operators have to exchange information regularly and at the right time to maintain a high level of TSA. In the current paper, we review different conceptualizations and operationalizations of TSA. Furthermore, we present a micro-world environment to explore the communication processes during individual and team work in order to

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investigate TSA. Initial results of the communication process of individuals are presented.

Measurement of Team Situations Awareness

Definition of TSA

In this paper, TSA is defined as a cognitive state within the team that influences the team's interactions (cf. Gorman et al., 2006). Therefore, it is seen as plausible to infer TSA, as a cognitive state, from observable behaviours within the team. These team behaviours, e.g. allocating tasks within the team (Salas et al., 1995), mainly rely on communication as the mediating process to fulfil the social function (e.g. "task allocation"). Good TSA means that team members have a comparable interpretation of cues and thus have a similar situation assessment (Salas et al., 1994). Besides TSA, individual team members still have individual situation awareness. The individual situation assessments can be synchronized either implicitly via shared mental models (e.g. Salas et al., 1994; Stout et al., 1999) or explicitly via communication of important information. One aspect of team communication that contributes to a similarity of individuals' situation assessments is the amount of shared information on which the individual situation assessment bases. Thus, an important aspect of TSA is the knowledge about information needs and information gaps of the other team members (Entin & Serfaty, 1999). A key indicator of good TSA is if and when relevant information is exchanged between team members. The term of relevant information relates to the task as well as the informational status of team members, as these are the important 'environmental conditions and system states with which the participant is interacting' (Pew, 2000, p. 34).

Overview of TSA measurement

A review of measures for TSA was conducted, with focus on approaches that use team communication as a mean to derive metrics of TSA. The review also includes related concepts, namely shared mental models or team mental models, adaption, coordination and problem solving within teams. An overview of the whole spectrum of TSA measures is given by Mohammed et al. (2010). Table 1 summarizes the reviewed approaches according to their general operationalization of TSA, their focus of communication analysis and the metrics derived. Methods differ in their general operationalization of TSA: first, whether the product of situation assessment is assessed as a certain cognitive state or state of knowledge, or second, whether the processes are assessed. Those processes are operationalized either as a reaction caused by a certain state of TSA or as a prerequisite of TSA. In the first case, it would be assumed that a team exhibits a certain communication style after they received team training, because their mental models and therefore their TSA were changed. In the latter case it would be assumed, that for example closed loop communication, as a distinct communication behaviour, would lead to good TSA as a result of these communication process. Furthermore, the observed team behaviours are compared between teams or are compared to normative behaviour.

Table 1: Overview of approaches for TSA measurement using communication

Operationalization of TSA	**Focus of communication analysis**	**Metrics**	**Examples**
Process as reaction: cognitive states of individuals become apparent in behaviour	Content of utterances in relation to generic model of task	Frequencies of utterances within content categories	(Prince et al., 1997); (Orasanu & Fischer, 1992, 1999)
		Sum of information linked to SA levels that are communicated	(Bolstad & Cuevas, 2010) (Bolstad & Endsley, 2003)
		Structure and phases of problem solving process	(Stempfle & Badke-Schaub, 2002)
	Speaker, function, content of utterances	Comparison of frequencies between two experimental conditions	(Farley et al., 1998)
	Communication as behaviour: Speaker, function, content, timing, structure	Transcript of behaviour in combination with situational constraints, knowledge etc.	(Gorman et al., 2006)
Process as reaction: good TSA leads to normative behaviour	Communication as behaviour: Speaker, function, content, timing, structure	Rating of observers Dichotomous scales (behaviour present / absent); Likert-Scales	(Wiener et al., 1991); (Dwyer et al., 1997); (Prince et al., 2007); (Cooke et al., 2001)
	Function & structure of communication	Proportions of categories (Anticipation as proportion of given to requested information)	(Entin & Serfaty, 1999); (Stout et al., 1999)
Process as prerequisite: process of team interaction leads to TSA	Communication as behaviour: Speaker, function, content, timing, structure	Knowledge networks	(Stanton et al., 2006); (Walker et al., 2006)
	Function & structure of communication ("closed-loop-communication")	Proportion of closed-loop-communication per information category	(Parush et al., 2010)

On the level "focus of communication analysis" the reviewed approaches differ with regard to the coding schemes used. A content analysis is normally conducted. In some approaches, the codes refer to the function of behaviour within the social process, e.g. request for information, and frequency metrics are calculated (e.g. Prince et al., 1997). In other cases, the codes relate the content of utterances to the (cognitive) tasks and this data is compared to standard operating procedures or normative task models (e.g. Orasanu & Fischer, 1992, 1999). Other approaches code the sequence of utterances, e.g. occurrence of closed loop communication (question-answer-readback) and compare occurrences to simple question-answer-structure (e.g. Parush et al., 2010). Another focus of analysis is the timing of communication in relation to the overall experimental task; e.g. the task is split into segments and only communication of one segment is rated as a relevant indicator of TSA (e.g. Stout et al., 1999).

Shortcomings of existing TSA measurement approaches

One shortcoming of the reviewed approaches is the operationalization of communication within the team and its theoretical connection to TSA. Communication, or in a broader sense team interaction, is a mediating process that facilitates other team behaviours (e.g. Hoc 2001). For instance, requesting information (e.g. Entin & Serfaty, 1999) or clarifying common goals (Stempfle & Badke-Schaub, 2002) are categories to code communication within the team. Those interactions are at the same time output of a certain cognitive state, and the input for the next cognitive state, e.g. by providing missing information or directing attention towards something. In this sense, all kind of team interaction, including non-verbal communication and technical information exchange, is a mean to establish TSA.

Another shortcoming is that content-related metrics, obtained through communication analysis, cannot be applied to other domains instantly as they are task or domain specific. A good metric for TSA should be applicable for a wide range of domains. For example, normative approaches developed for the analysis of TSA of cockpit crews rely on the highly standardized procedures within aviation. Behaviour shown by a cockpit crew can relatively easily be compared to the so-called Standard Operating Procedures (SOP). Within the medical domain, TSA is also a relevant construct, as the environment is dynamic and decisions are safety critical. Nevertheless, the work of the surgeon is less standardized. So, it is not feasible to apply the idea of SOPs as a way of analysing communication. The categories to analyse communication should be as generic as possible but still provide insights into TSA.

Methodological approach to investigate Team Situation Awareness

The approach to investigate TSA, presented in this paper, was developed to fulfil two demands: (1) team communication behaviour should reflect the team's cognitive state TSA and (2) the analysis of communication should allow a transfer to multiple domains. Therefore, requirements for the experimental set-up are defined as following: objective measures of the interaction process should be derived and experimental runs conducted with the task should be comparable. The interaction process of participants within the task has to be clearly defined and understood. Nevertheless, ecological validity has to be apparent. Taken together, the task should be dynamic and complex but allow on the same time a high degree of experimental control. Factors of the task that should be controlled are for instance: the task complexity, the degree of task interdependence and the modus of interaction.

Description of the experimental task

As an experimental task for investigation of team interaction processes, a micro-world set-up was chosen. Micro-worlds are the link between laboratory experiments and complex high-fidelity simulations (Gray, 2002) and have been used to apply constructs of basic psychological research to applied sciences, like human factors in aviation (Möhlenbrink et al., 2009; Oberheid et al., 2009). The micro-world MAGIE EnRoute (Oberheid et al., 2011) was used, to implement a team task. MAGIE EnRoute refers to the workplace of an en-route air traffic controller. Within a generic airspace, two or more operators are responsible for the save flight of their aircraft. This set-up covers some aspects of a novel air traffic management concept called “Sectorless ATM” (Birkmeier et al., 2011).

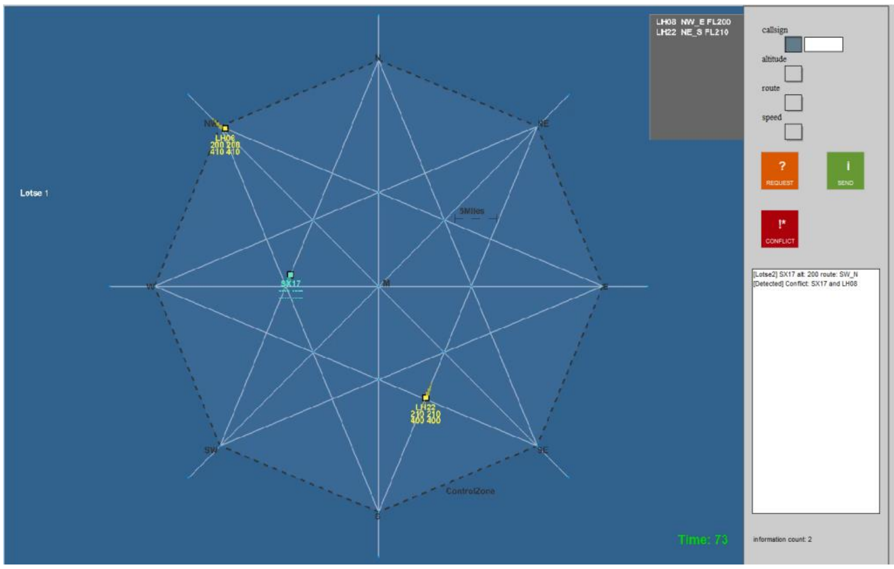

Figure 1 Graphical User Interface of MAGIE EnRoute

Aircraft fly with a certain speed on predefined routes in a certain altitude through the airspace. Aircraft can have conflicts, i.e. some prescribed separation distance between two aircraft is violated. These conflicts should be detected by the human operator as early as possible. Operators have to coordinate their work in a team in order to be able to detect, and to solve those conflicts. To identify whether two aircraft are going to have a conflict, operators have to exchange altitude information of the aircraft, as well as information about the routes. Otherwise, the controller’s assessment of the traffic situation based on information available to him, is ambiguous (conflict/ no conflict) until the conflict actually occurs. Each participant has its own display. The display of the micro-world for one participant is depicted in Figure 1. Next to the radar screen of the generic airspace, each participant has a communication tool to request and send aircraft altitude, route or speed data. This communication tool could be replaced by a chat tool or natural speech.

Aspects of TSA

The micro-world provides an environment, where team members do not have full access to all information required. A participant has full access to all information about his/her own aircraft (altitude, speed, and route) but only limited information about aircraft controlled by others. Information that can be gathered by observing the other aircraft is the actual position of aircraft in the airspace and approximate speed. In some cases, the route the aircraft will take is fully determined by the position within the airspace, in other cases the route is ambiguous because the aircraft might turn and take another route. Prior to the simulations, participants are instructed about the rules where aircraft can turn. Thus, participants have to identify their own information needs and request information from the team partner in order to gain unambiguous interpretation of the traffic situation. The micro-world also allows for conflict resolution, by advising new routes, altitude or speed to the aircraft. This conflict resolution needs to be coordinated between team partners.

Two aspects of TSA are represented in this task. First, the interpretation of the current situation within the team depends on the information, which is shared between the team partners. Some information, e.g. altitude of an aircraft, needs to be explicitly made public by communicating it, as a prerequisite for a correct situation assessment. As long as this information is not shared within the team, team members assess the situation on the basis of different information and therefore their situation assessment can differ significantly (conflict/ no conflict). Second, as time pressure exists within that task, pro-active provision of relevant information to the team member is efficient communication behaviour to establish such a shared information basis. This implies, that not only the own but also the others' information needs have to be considered.

The micro-world is very close to the specific task of the en-route controller. Nevertheless, it is assumed that empirical results of communication behaviour within this task can be applied to other domains and tasks as long as they are characterized by the following features: the task requires coordination within a team, the environment is dynamic, decisions have to be made under time pressure so the timing of information is important, monitoring of the environment and or a system is a substantial part of the task and operators only partially have direct access to information about the environment and or the system.

Pilot study

The sample of the pilot study consisted of 16 employees of the German Aerospace Centre (8 women, 8 men) with a mean age of 28 years (*SD* = 6 years).A stepwise empirical research is favoured to understand the influence of the different factors, described above, onto the observable team communication behaviour. As a basis, it should be understood, in how far communication behaviour of individuals differs within such a task in order to build teams of two or more operators, whose individual behaviour is known. Within an interactive team situation, the behaviour of the individual team member always is influenced by the behaviour of the other team members. For this reason, a set-up was chosen that allows for investigation of individual behaviour within the task in isolation.

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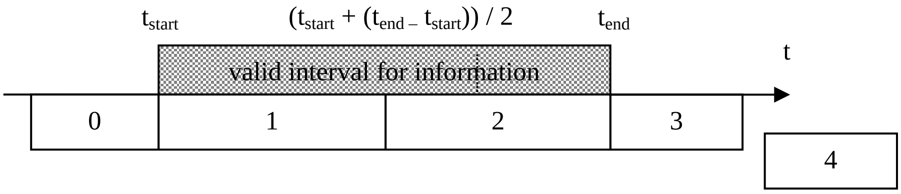
An explorative analysis is conducted, to test whether there are observable differences between the communicative behaviours of individuals and if those can be explained with personal traits and social attitude. The team work required was reduced to the subtask requesting information. The team partner was replaced by an automated script, acting like a confederate. The script responded to the questions of the participant with a constant delay of 10 seconds.

Scenario Design. A scenario of 20 minutes was generated that included seven traffic situations consisting of a pair of aircraft that has a potential conflict. Each traffic situation is described by the parameters time to conflict (TTC) and whether the route of the other aircraft is ambiguous (Amb.: yes), unambiguous (Amb.: no) or partially ambiguous (Amb.: part) (cf. Table 2). For each pair of aircraft, the participants had to decide, whether a conflict will occur or not. For this decision, the participant needs to gather information. A normative communication model was developed, which predicted for every data (altitude, route and speed for each aircraft) a time interval, where the data is relevant information that would have to be communicated to solve the task accurately. For this interpretation, the perspective of the participant was taken regarding the actual information s/he has about the traffic situation and information s/he needs to evaluate a traffic situation correctly. Furthermore, it was assumed, that only novel information was relevant, as it gives the participant more information than s/he had before. So, information the participant could gather about the other aircraft by observation would not be relevant and should not be communicated.

Experimental design. All participants answered a questionnaire including biographical data, personal traits and attitudes towards teamwork at least one day in advance of the experiment. At the day of the experiment, subjects received detailed instructions about their task and the rules of the micro-world. They conducted a training of 20 minutes that included all possible routes aircraft can take and presented an example of each conflict situation of the experimental run. Then, participants conducted the experimental task.

Measures. As performance criteria, the number of correctly detected conflicts (N corr) and the time-distance of the detection to the actual occurrence of the conflict in seconds (T_{mean}) as well as in relation to the interval given by TTC (T_{rel}) were calculated. The process of information exchange is described with quantitative and qualitative metrics. Altogether, each participant had 21 possibilities for data exchange during the scenario (3 information types (altitude, route, speed) * 7 traffic situations). During the simulation each communication act is recorded with time, sender, aircraft callsign and type of information. As quantitative metrics for each traffic situation it is calculated, how many participants requested the specific information (Alt n, Route n, Spe n, min = 0, max = 16). In order to discriminate individual behaviour, for each participant and possible data exchange the time distance to the start of the normative communication interval (t_{start}) is calculated. As only little is known about the meaning of this quantitative measure – is a difference between participants of 10 seconds meaningful with regards to TSA - qualitative metrics of the communication behaviour are calculated by classification into five categories, according to the scheme shown in Figure 2. The classification results in the variable “timing of information”.



0 = too early, 1 = rather early, 2 = rather late, 3 = too late, 4 = not requested at all

Figure 2 Classification scheme for variable ‘timing of information’

To assess individual traits and personality, a set of standardized scales were used. Attitudes towards teamwork were assessed with the questionnaire FIT (Mohiyeddini, 1997), consisting of two subscales “Willingness to Teamwork” (“Will”) and “Reservations against Teamwork” (“Res”). Personality was assessed with the Factor Extraversion (“Ext”) and Agreebleness (“Agree”) of the BIG Five Short Scales (Rammstedt & John, 2006). Furthermore, the scale “Need for Cognition” (“NfC”) (Bless et al., 1994) was used.

Results

Descriptive data for the different situations of the scenario are summarized in Table 2. All situations were assessed correctly by participants, except two (Situation 2 and 4). The low numbers of correct assessments for situation 2 are due to the scenario design, as it was at the end of the simulation and participants could not end the assessment in time. Nevertheless, most participants requested data for this situation, so the situation is included in the further analysis of the communication behaviour. Regarding situation 4 two participants did not detect the conflict correctly. As this conflict occurred at the beginning of the scenario it could be due to usability problems, because both participants indicated, that they assume a conflict.

Table 2 Descriptive data of traffic parameters, communication process and performance data per traffic situation

traffic situation			**communication process**			**performance**		
No	**TTC[s]**	**Amb**	**Alt n**	**Rou n**	**Spe n**	**N corr**	**T_{mean} *(sd)* [s]**	**T_{rel} [%]**
1	230	no	16	11	6	16*	--	--
2	-	no	13	10	6	3+	--	--
3	150	no	16	9	3	16	-78 *(17)*	48
4	190	part	15	8	5	14	-72 *(28)*	62
5	400	part	16	10	5	16	-199 *(64)*	50
6	200	part	16	8	5	16*	--	--
7	240	yes	16	13	6	16	-101 *(61)*	58

* situation correctly assessed as “no conflict”

\+ situation assessment could not be completed due to end of simulation run

All situations with a true conflict were detected after 50 - 60% per cent of the predicted interval, so participants followed the instruction of detecting conflicts in advance. The different types of information were requested with different frequencies. Altitude (Alt n) was requested most often in all situations; followed by route (Rou n) and speed (Spe n) information. This ranking is plausible, as speed was no relevant information within the task, but altitude was information that could not be derived by monitoring the radar screen and had to be actively asked. No differences is evident for the frequency of requesting the route (Rou n) comparing the unambiguous and partially ambiguous situations.

To assess the individual communication behaviour, a cluster analysis was performed with the nominal variable timing of information. The implementation of the Ward-algorithm within the library “stats” of the statistical software “R” (Murtagh, 1985) was used for clustering. A dendrogram was used for evaluating the results. Analysis yielded three clusters. In a next step, these clusters were taken as a grouping variable, in order to develop a description of the communication behaviour, shown within these clusters. The absolute frequencies of time categories for each participant were analysed, whether they provide evidence for the clusters (see stacked bar diagram depicted in Figure 3).

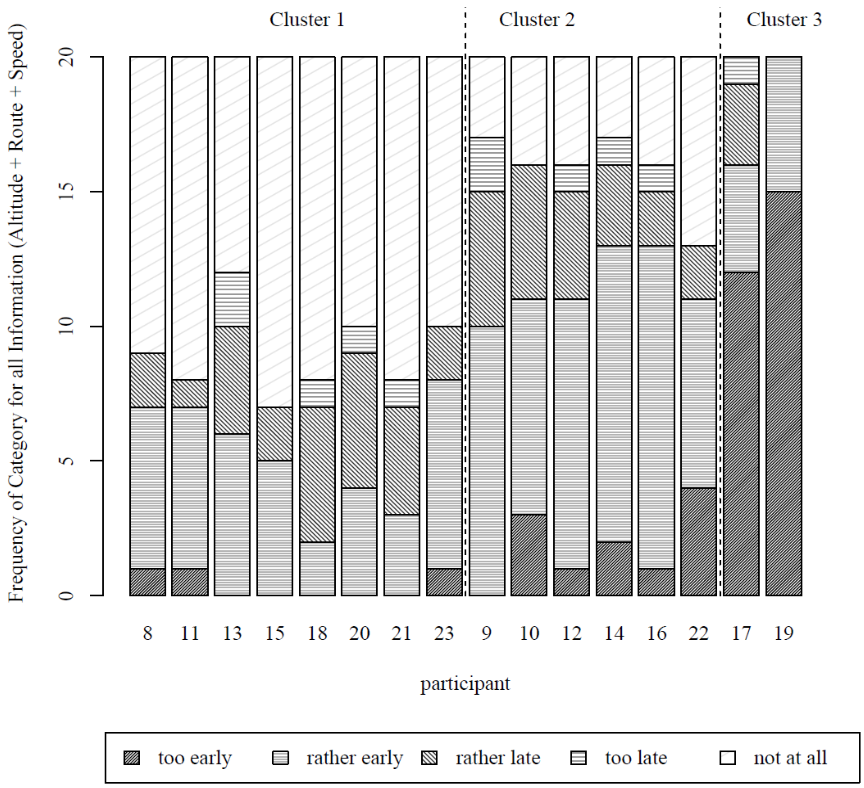


Figure 3 Distribution of the variable’ timing of information’ per participant

Qualitative descriptions of these behaviours were developed. Cluster 1 describes behaviour of omitting a quite large number of information (high values in category “not at all”). Cluster 2 comprises those participants that requested much information within the first part of the predicted interval (high values in “rather early”) . Cluster 3 can be described as participants that requested a lot of information even before the normative model predicted their relevance (high value in “too early”). This cluster is very small (n = 2); but the behaviour is very distinct from the rest of the sample.

For further investigation of the relationship between communication behaviour and personal traits, the identified clusters were used as grouping variables for personal traits. Mean values for the sample, as well as the clusters are summarized in Table 3. None of the variables correlated significantly with each other. Because of the small sample size of cluster 3 (n = 2), T-Tests were only conducted for cluster 1 and 2. Mean values of the clusters were compared with Welch Two Sample T-tests. No significant differences could be found, except for the scale “Need for Cognition. Cluster 1 has a significant lower mean value than cluster 2 (M_1 = 9 (SD_1 = 5,24); M_2 = 18 (SD_2 = 4,82); t = 3.3; p = <.01 indicating a lower need for cognition within cluster 1 compared to cluster 2.

Table 3 Mean values for sample and clusters for personal traits

Cluster	**n**	**Ext**		**Agree**		**NfC**		**Will**		**Res**	
		m	***sd***	***m***	***sd***	***m***	***sd***	***M***	***sd***	***m***	***sd***
1	8	3,7	0,6	3,4	0,74	**9,0***	5,2	17,9	1,73	10,9	2,12
2	6	3,2	0,8	3,6	0,61	**18,0***	4,8	16,7	1,51	10,8	2,0
3	*2*	*2,8*	*1,0*	*3,8*	*1,06*	*6,5*	*5,0*	*18,5*	*0,71*	*13,0*	*0,0*
sample	**16**	**3,4**	**0,8**	**3,4**	**0,70**	**12,1**	**6,7**	**17,5**	**1,63**	**11,1**	**2,0**

Discussion

Methodological approach

The approach for investigating TSA, presented in this paper, uses metrics derived by the communication processes within a team task. Those interactions within the team are the prerequisite of TSA, as they provide the necessary information basis so that ambiguous situations can be interpreted correctly. Different communication behaviours can therefore lead to a different information status within teams. The results of the pilot study showed, that individuals show different communication styles. Regarding the detection of conflicts, these different styles did not lead to differences in the performance. Nevertheless, within an interactive team situation, where two team members have to exchange information, the results might be different. The strategy of data analysis used within the pilot study (use of a normative communication model, classification of time data into qualitative metrics) provided meaningful results. It seems promising, that within the controlled setting of the experimental task and the clear understanding of available and needed information in order to solve the task, the link between communication data and TSA can be established.

Communication behaviour of individuals

The pilot study explored, whether participants show different communication behaviours and in how far this behaviour is moderated by personal traits. Results of the cluster analysis show, that distinct communication behaviours were apparent within the sample. Furthermore, it was possible to describe the clusters in terms of different strategies performing the task: 1) highly select needed information, 2) ask more information in time than really necessary and 3) ask all information even before a conflict is likely to happen.

An influence of personal traits on the different communication behaviour could not be found, except for the scale "Need for Cognition". But, in general the sample was quite homogenous regarding their personal traits and social attitudes. Whilst individuals show different behaviours within the task, these behaviours cannot be explained with different attitudes towards teamwork or personal traits, except "Need for Cognition". Need for cognition describes whether persons enjoy cognitive tasks; the highest score was found for the cluster 2 that asked a lot of information relatively early. With regards to the task "requesting relevant information", this behaviour requires less effort in selecting the relevant information in advance, but more effort in terms of cumulating all available information into an interpretation of the situation. The scale "Need for Cognition" will be used in further studies to control the composition of teams.

Outlook

The pilot study gave first insights into the communication behaviour of individuals whilst requesting information. Consequently, the follow-up study will analyse the interaction process of two individuals within the experimental setting. The insights into different communication behaviours of individuals will be used to control the composition of teams. It is of interest, which communication behaviour a team, consisting of two individuals with different communication behaviours, develops over time. Furthermore, it has to be analysed whether coordination, e.g. during solving the conflict, is influenced by these differences in individual communication behaviour. It further has to be examined, in how far this approach is feasible for other domains, e.g. analysing the interaction data of a medical team.

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