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Executive summary

Air Traffic Control Shared Mental Models: Effects on team behaviour, communication, and performance in a game environment

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Problem area
Air traffic control (ATC) is a complex task which requires team work of highly trained and skilled individuals. Developments towards future air traffic management increasingly require a team to timely select and share relevant information. Team members need accurate shared knowledge about each other's tasks, mentally represented by a so-called Shared Mental Model (SMM). The dynamics of Shared Mental Models of Air Traffic Controllers (ATCOs) during task execution is rarely studied. We need more insight in these dynamics to facilitate efficient teamwork of future ATC teams.

This report is based on a presentation held at the 29th European Association of Aviation Psychology Conference, Budapest, 20 – 25 September 2010.

Description of work
The present study focuses on how shared knowledge is related to team behaviour and communication. Twenty-six teams of three played the game TeamTris, which has similarities with the ATC task, but is less complex and does not require actual ATC knowledge. Participants were randomly assigned to one of two conditions. In the SMM condition participants explicitly shared task and team information, whereas in the non-SMM conditions team members received information only about their individual task. All teams played three TeamTris sessions. Communication, team behaviour and team performance were recorded.

Results and conclusions
Results show that team members in the SMM condition had more accurate and similar SMMs. There were no differences in communication, behaviour or performance. However, detailed analysis showed that performance of the SMM teams initially dropped in the second session and increased again in the final session. We assume that team members in the SMM condition experienced additional task demands due to team work requirements. Performance increased again when team members learned to handle both individual task execution and cooperation.

Applicability
Two major implications for ATC emerge from the present study. First, teams do not necessarily develop shared and accurate knowledge due to mere team task exposure. Teams also need explicit moments in which they can discuss common strategies. We suggest putting more emphasis on debriefings, even if everything went well during a shift. Second, we showed that teaming is cognitively demanding. We propose that training team work is crucial before controllers will work together in the field. The current focus during ATCOs training lies on individual competence development. Both implications should be taken into account in future Air Traffic Management. Facilitating SMMs can help bringing unknown team members in line in a challenging future.

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Air Traffic Control Shared Mental Models: Effects on team behaviour, communication, and performance in a game environment

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Summary

Air Traffic Control (ATC) is a complex task which requires team work of highly trained and skilled individuals. Developments towards future air traffic management increasingly require a team to timely select and share relevant information. Team members need accurate shared knowledge about each other's tasks, mentally represented by a so-called Shared Mental Model (SMM). The present study focuses on how shared knowledge is related to team behaviour and communication. Twenty-six teams of three played the game TeamTris, which has similarities with the ATC task, but is less complex and does not require actual ATC knowledge. Participants were randomly assigned to one of two conditions. In the SMM condition participants explicitly shared task and team information, whereas in the non-SMM conditions team members received information only about their individual task. Communication, team behaviour and team performance were recorded. Results show that team members in the SMM condition had more accurate and similar SMMs. There were no differences in communication, behaviour or performance.

Contents

1 Introduction

Air Traffic Control (ATC) is a complex and dynamic task which demands highly skilled operators. Both researchers and practioners aim to design effective ATC selection and training methods. They typically focus on individual controllers and underestimate the importance of team work. Effective teams generally show closed-loop communication, monitor their performance, and behave adaptively and supportively (Salas, Rosen, Burke, Nicholson, & Howse, 2007). Such behaviours suggest that the team members have a so-called Shared Mental Model (SMM). SMMs comprise multiple mental models about team and task elements that must be shared among team members (Mohammed, Ferzandi, & Hamilton, 2010). Justen and colleagues (2010) have suggested five separate types within the dynamic domain of ATC: Equipment, Task, Team Interaction, Team and Situation Mental Models. Air Traffic COntrollers (ATCOs) confirmed that these models are relevant to describe many team- and task-related concepts in ATC. Research has supported the positive relation between SMMs and team performance (e.g. Lim & Klein, 2006; Mathieu, Rapp, Maynard, & Mangos, 2010; Smith-Jentsch, Mathieu, & Kraiger, 2005), but much remains unclear about the role of communication and overt behaviour in SMMs. Even though some studies (e.g. Espevik, Johnsen, Eid, & Thayer, 2006) have investigated the interaction between SMMs and communication and/or behaviour during actual task execution, SMM measures are commonly isolated from the task and assessed on an abstract level (e.g. Mathieu, Heffner, Goodwin, Cannon Bowers, & Salas, 2005). According to Justen et al. (2010) this static assessments, such as paired comparison ratings, fail to measure actual knowledge application during task execution. These authors differentiated between two levels of SMMs, namely the *Reflectional level*, which is an individuals' theoretical description of knowledge, and the *Action level*, representing the dynamics of knowledge application during task execution. Assessing the *Reflectional level* only, might not be sufficient to fully capture SMMs. Moreover, it may explain why some investigations have not yielded the expected positive effects of SMMs as Mathieu et al. (2010) noted. Although many studies interpret the effects of SMMs in behavioural terms, such as coordination benefits or concise communication, only a minority of studies investigate actual communication behaviour.

We take the view that analysing communication and team behaviour should provide insights in the *Action level* of an existing SMM. These process variables, i.e. communication and behaviour, are necessarily to be assessed on a team-level. We add to the existing literature by proposing three pillars of accurate SMMs: theoretical knowledge of the team task, cooperative experience with the team task, and active and reflective communication.

Especially if team members actively communicate during task execution and reflect about the task afterwards, component individual should bond into an effective team.
The future European airspace will be sectioned by functional airspace blocks rather than national frontiers. As a consequence, teams of ATCOs will be dispersed across different European facilities. Furthermore, there is a clear trend of increasing application of datalink communication in aviation. This means that both cooperative task experience and voice communication will diminish. This study attempts to capture some of the impacts of these foreseen changes. Although these changes apply for the whole air traffic management system, the current study focuses mainly on area control.

Finally, we differentiate between SMM accuracy and similarity. If individuals bring inaccurate knowledge into a team, shared knowledge will also be inaccurate (Lim & Klein, 2006). Therefore, similarity and accuracy should be assessed separately to judge the quality of a SMM.

The primary goals of this study are to investigate the positive effects of explicit moments of knowledge sharing on SMM, via communication, team behaviour and performance. Accordingly, we hypothesized the following: (1) Explicit moments of knowledge sharing lead to more accurate and similar SMMs. If the first hypothesis is true we further assume that (2) Explicit moments of knowledge sharing lead to more efficient communication; (3) Explicit moments of knowledge sharing lead to more efficient behaviour; and (4) Explicit moments of knowledge sharing lead to better performance.

2 Method

Participants

78 students (57 female, 21 male) of Maastricht University participated in the study in exchange for course credits or 10€ vouchers. Participants' average age was 22 years (*SD* = 6). They were randomly assigned to three-person teams to form a total of 26 teams.

Task

Teams were involved in the dynamic PC game TeamTris (Figure 1). TeamTris is a cooperative version of Tetris™: A Planner selects useful shapes

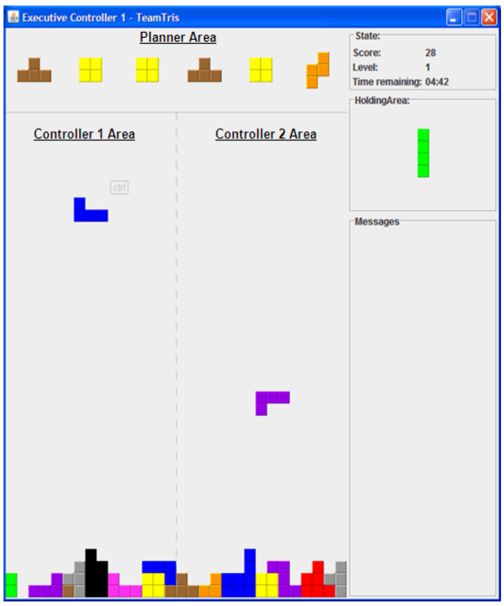

Figure 1. Interface of TeamTris

for the two controllers who navigate the shape to the ground. Shapes can be moved horizontally, downwards or rotated clockwise. Controllers are responsible for their assigned sector, but the team members attempt to build a conjoint line at the bottom of the screen. The game contains three special shapes which either Controller 1, Controller 2, or neither can rotate. This shape may be exchanged between controllers by merely moving it across the line which divides both sectors. We developed TeamTris specifically to study team processes in ATC because it is less complex and does not require actual ATC knowledge. Various ATC competences are designed into the game. For instance, the Planner plans and decides to select useful shapes for the controllers. A controller needs to be aware of the activities and sector contents of the other controller, as such requiring situational awareness.

Procedure

Each team was assigned to one of two conditions (SMM condition or non-SMM condition). The study involved three phases. Phase 1 – the baseline measure – was the same for all teams. Team members individually read their own task description with all relevant information to complete the assigned task. In addition, each description included 2 to 3 team-related knowledge elements which differed per function. The team then practiced TeamTris for 10 minutes to familiarize themselves with the game. In phase 2, team members in the SMM condition read each others' task description, whereas participants in the non-SMM condition reread their own task description. Again a team played TeamTris for 10 minutes. In the third phase a team in the SMM condition first discussed various team and task aspects such as strategy, meta-communication, or workload distribution. Teammates in the non-SMM condition summarized their own task. This was followed by playing a final 10 minutes of TeamTris. At the end of the final session, all participants completed a questionnaire on measures for mental model similarity and accuracy. Communication was voice recorded during the entire experiment.

3 Measure

Performance

Teams completed three games of TeamTris. Each game lasted 10 minutes and all teams avoided game over. Team performance for each team was measured by the sum of points earned during the last two games. Points could be earned by clearing lines. Clearing more lines simultaneously yielded more points. We assigned penalty points for collision of two moving shapes, collision of a moving shape with the wall, and if the Planner was too late with selecting the next shape before the operating shape reached the ground.

SMM Accuracy and Similarity

Participants completed a 9-item questionnaire regarding task and team knowledge at the end of the final session. Task related questions concerned procedures such as: "If two lines are cleared at the same time, your team awards the same amount of points as when three lines are cleared simultaneously". Items on team related knowledge queried team skills such as: "Which shapes can not be rotated by Controller 1?". This measure indicates how accurately participants read the task instruction, i.e. SMM accuracy, and whether they have communicated this knowledge with the others, i.e. SMM similarity. The three answer possibilities were right, wrong, and I don't know. SMM accuracy was the number of correct responses per team. SMM similarity was the number of agreements per team – independent of the accuracy of the responses.

Team process

Communication: We recorded voice communication during the experiments and transcribed it afterwards. We coded requests and offers in the transcripts of 10 teams and computed the anticipation ratio. Earlier research (Entin & Entin, 2001) showed that the anticipation ratio, which is the quotient of offering and requesting information, is useful for understanding team communication. A team member who anticipates the information needs of the others will offer this information before it is requested.

Behaviour: To operationalize behaviour, we rated 9 team behavioural statement based on Salas et al. (2007) approach on markers for team cognition. At least one statement corresponds to one of the SMM types relevant in ATC (Justen et al., 2010). Team behaviour was the sum of all statement and sessions.

4 Analysis

We conducted independent sample t-tests to investigate differences between the conditions. In addition, we performed a session (3) x condition (2) ANOVA to test performance developments across the session.

5 Results

The descriptives and mean differences of the assessed variables are shown in Table 1.

TABLE 1.
Descriptive Statistics and Mean Difference for All Study Variables

		Total Performance	*SMM Similarity*	*SMM Accuracy*	*Anticipation Ratio*	*Behavioural Markers*
N	1	13	13	13	4	4
	2	13	13	13	6	6
M	1	209.15	10.85	16.69	1.13	67.50
	2	272.54	8.92	14.31	0.76	48.67
SD	1	209.72	1.41	2.25	.12	9.33
	2	229.22	2.53	3.07	.64	25.48
t		-.74	2.26*	2.40*	1.37	1.39

Note. N = number of subjects. *M* = Mean. *SD* = Standard deviation. *t* = difference statistics. SMM = shared mental model. 1 = SMM condition. 2 = non-SMM condition
*p < .05.

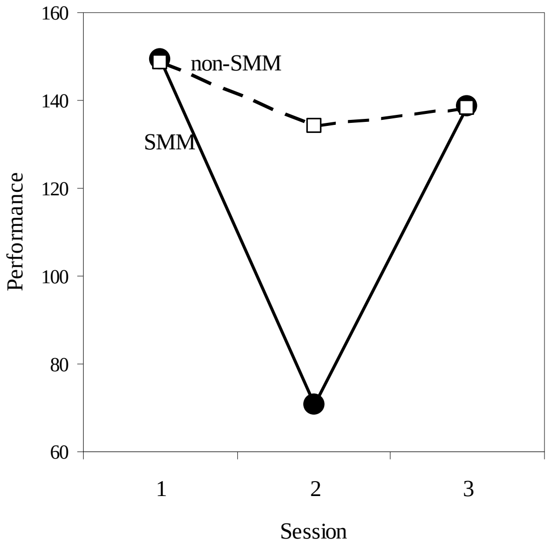

Figure 2. *Performance as a function of session*

Teams in the SMM condition shared significantly more knowledge (M = 10.85, SD = 1.41) than teams in the non-SMM condition (M = 8.92, SD = 2.53, t(18) = 2.40, p = .027). In addition, the t-test revealed that SMM accuracy was significantly higher in the SMM condition (M = 16.69, SD = 2.25) than in the non-SMM condition (M = 14.31, SD = 3.07, t(24) = 2.26, p = .033). There were no main condition differences for total performance, t(24) = -.736, p = .469, the anticipation ratio, t(6) = 1.37, p = .225, or behavioural markers, t(8) = 1.39, p = .201. However, figure 2 suggests a non-linear relation between performance and session. In effect, performance in the second session was lower than in the practice and in the final session. This was statistically substantiated by a significant quadratic effect of session, F(1, 24) = 5.12, p =

.033. Figure 2 also suggests that this non-linear effect of session applies only to the SMM condition. This turned out to be a trend as confirmed by the quadratic interaction between session x condition, $F(1, 24) = 3.07$, $p = .09$.

6 Discussion

The aim of this study was to investigate the role of explicit moments of knowledge sharing on SMMs, communication and team behaviour in a game environment. Results show that SMM similarity and accuracy were facilitated by explicit moments of information exchange, namely by receiving each other's task description and having a team discussion (Hypothesis 1). Team members developed a better understanding of each other's functioning and had similar views on task procedures and limitations.

Detailed analysis across sessions showed that performance of the SMM teams initially dropped significantly in the second session and increased again in the final session. Although contrary to our expectations (Hypothesis 4), this finding makes sense as the complexity level, including the requirements to cooperate, was lower during the practice phase (see Figure 1). Furthermore, team members in the SMM condition may have experienced additional demand by multitasking. They focused on their individual task, but simultaneously had to integrate the theoretical team knowledge they had read before. In the final session, performance in both SMM conditions was equal again. Two things might have happened. First, SMM teams improved individual task performance and consequently had spare capacity to focus on team work. Alternatively, the team discussion facilitated the integration of the theoretical knowledge, so that team members could now effectively apply this knowledge. Future research should reveal whether this improvement will continue in time and the SMM teams will start to outperform the control groups when sessions are added to the three of the present study.

We failed to find condition differences of the team process variables (Hypothesis 2 & 3). All teams communicated equally well and displayed similar behaviours. This is surprising since our manipulation effectively influenced SMM similarity and accuracy. Based on earlier research (Espevik et al., 2006), we would expect that SMM teams efficiently transfer their shared team knowledge into meaningful actions and also communicate more efficiently than non-SSM teams. Again the multitasking demand of integrating team work and individual task execution, may have led to averaged communication behaviour. These results are is in line with the 2-level approach of SMMs (Justen et al., 2010) we outlined earlier. We proved, that team members, who explicitly exchanged knowledge, developed a more accurate and similar SMM on the

Reflectional level. They had the same accurate view on simple task rules for example, which we could easily assess with a questionnaire. The results confirm that team members' *Reflectional* SMMs are different from their *Action* SMMs. Moreover, measuring one level does not necessarily justify making assumptions about the other level. As Justen and others (2010) suggested, the *Action level* of SMMs is the applied knowledge in dynamic situations. Perhaps team members in the current study were unable to integrate their knowledge on the *Action level* as this depends on more prolonged exposure to dynamic situational events and team members' behaviour. Future research should show whether more mature teams can actually take advantage of their shared knowledge.

Two major implications for air traffic control emerge from the present study. First, teams do not necessarily develop shared and accurate knowledge due to mere team task exposure. Teams also need explicit moments in which they can discuss common strategies, individual preferences and workload distribution. Such sessions are useful as they offer operators enough time and possibilities to discuss relevant topics that complement the basic task requirements. Although an immediate performance benefit may not been observed instantly, it facilitates operators to develop a similar work approach and understand each others functioning. It is common that ATCOs debrief their shift if there have been unforeseen events. We suggest putting more emphasis on debriefings, even if anything went well during a shift. Second, we showed that teaming is cognitively demanding which can have initial negative effects on performance when a team is freshly assembled. It is vital that ATC team members know each other and understand how they effectively cooperate in a specific team. We propose that training team work is crucial before controllers will work together in the field. The current focus during ATCOs training lies on individual competence development. Both implications should be taken into account in future Air Traffic Management. European initiatives such as Single European Sky, including functional airspace blocks, will ask for more inter-facility team work within Europe. Teammates with different backgrounds and nationalities will work at geographically distributed locations and communication will be diminished to standardized datalink messages. Facilitating SMMs can help bringing unknown team members in line in this challenging future (Espevik et al., 2006).

Although TeamTris was specifically developed to model the ATC task, the generalizabilty of our results is limited. The ATC task is more complex and our selection of the process variables was limited. Subsequent investigations should test whether the found mechanisms also apply to the ATC task with experienced ATCOs.

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