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The effects of general mental ability and memory on adaptive transfer in work settings

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To handle complex technical operations, operators acquire skills in vocational training. Most of these skills are not used immediately but at some point later; this is called temporal transfer. Our previous research showed that cognitive abilities such as general mental ability (GMA) and memory are good predictors of temporal transfer. In addition to temporal transfer, operators also have to solve non-routine and abnormal upcoming problems using their skill set; this type of transfer is called adaptive transfer. Based on previous findings, it is assumed that GMA and memory will affect adaptive transfer as well. Thirty-three engineering students learned how to operate a complex technical system in normal operation with either a fixed or a contingent sequence. After two weeks, all participants had to adapt their learned skills to handle the adaptive transfer task, which was not initially trained. It was shown that high GMA positively predicted adaptive transfer, but no effect of memory was found. This implies that GMA is required to solve new complex tasks using a learned skill set. The findings are in line with studies that showed an effect of GMA on temporal transfer.

Keywords: adaptive transfer, mental abilities, complex task, process control, complex skills

Operators, pilots or surgeons have to apply complex tasks in their daily work. Such complex tasks include controlling the system of refinery or chemical plants, controlling and flying an airplane, or performing surgeries. These complex tasks can be described by a number of sub-tasks, sub-sequences of sub-tasks, and integration of sub-tasks, and require the coordination and realization of predefined objectives, attention and simultaneous information processing (Kluge, 2014). Employees have to handle complex tasks in both routine and non-routine situations (Kluge, 2014): In routine situations, complex tasks are performed regularly e.g. operators monitor, control, adjust the system and follow often used Standard Operating Procedures (SOPs), or surgeons suture surgical wounds after performing a well-known appendectomy. Non-routine situations, on the other hand, can be divided into situations which require temporal or adaptive transfer: 1) Usually, non-routine situations occur in the medium or long term after the initial skill acquisition and require *temporal transfer*, meaning that such situations have to be handled after longer periods of non-use. 2) Non-routine situations that require *adaptive transfer* are novel to the operator. Adaptive transfer is needed if skill components have to be applied in dynamic, complex and unpredictable situations that have not been previously encountered (Bolstad, Cuevas, Costello, & Babbitt, 2008;Ivancic & Hesketh, 2000; Kluge & Burkolter, 2013; Kluge, Sauer, Burkolter, & Ritzmann, 2010). Adaptive transfer in a novel situation requires operators to understand the upcoming event that has never occurred before, quickly generate an appropriate reaction to ensure system safety on the basis of their knowledge, and adapt acquired skills to the novel situation (Vicente & Rasmussen, 1990). Such an adaptive transfer is required, for instance, when a surgeon has to handle a complication that has never arisen before. A similar description of adaptive transfer can be found for complex problem solving, which requires the coordination of complex cognitive operations like action planning, strategic development, knowledge acquisition and evaluation in order to achieve a goal (Funke, 2010).

Temporal transfer requires recognition of the situation, system and upcoming events, and the selection and execution of correct SOPs in terms of memory of rule-based knowledge based on “if-then” associations. Adaptive transfer, by contrast, requires operators to solve problems which consist of situations that are opaque, dynamic and interconnected and call for complex problem solving skills (Fischer & Neubert, 2015; Wüstenberg, Greiff, & Funke, 2012).

In conclusion, complex tasks in non-routine situations require adaptive transfer if operators have to handle complex tasks for which they are not specifically trained and of which they have no personal previous experience. In this case, operators have to retrieve and use an existing skill set in order to have a basic understanding of the task and a starting point for finding new solutions.

Previous research findings on the relation between solving new problems and general mental ability have been conflicting (Beckmann & Guthke, 1995; Wittmann & Hattrup, 2004; Wüstenberg et al., 2012). However, in the area of applied complex process control tasks, only a small amount of research has investigated the effect of general mental ability on adaptive transfer (Gonzalez, Thomas, & Vanyukov, 2005), despite the fact that such findings could be directly applied for personnel selection. Therefore, it is a highly relevant topic in this area: Past accidents in nuclear power plants or refineries indicate that operators were often unable to transfer their skills to a novel situation. On the other hand, the absence of many more accidents suggests that adaptive transfer has often gone very well in the past (e.g. U. S. Chemical Safety and Hazard Investigation Board, 2007). For a better understanding of why adaptive transfer goes well in some cases and badly in others, the present paper investigates the effect of general mental abil-

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ity. As recent studies have demonstrated the effect of general mental ability and memory on temporal transfer, the present paper investigates whether participants are able to solve a new problem (adaptive transfer) in a process control task using their present skill set, and whether their performance is affected by general mental ability and/or memory (Hülsheger, Maier, & Stumpp, 2007; Kluge, Frank, Maafi, & Kuzmanovska, 2015). As such, the study contributes to existing research by analysing the effect of general mental ability and memory in a complex task embodied by a simulated process control task.

In the following, it is introduced how operators acquire a set of skills required to solve an adaptive transfer. Subsequently, determinants of adaptive transfer and the effect of general mental ability and memory on performance in complex tasks and adaptive transfer are described.

Acquisition of complex cognitive skills

To operate in a control room skilfully, operators acquire complex cognitive skills (van Merriënboer, 1997). Complex cognitive skills are described as a combination of cognitive and motor sub-skills, although most of them are cognitive sub-skills and at least some skills require conscious processing (van Merriënboer, 1997). The concept of complex skill is similar to Dörner and Güss' (2013) concept of action schema as the basic unit of action. Similar to complex skills, an action schema consists of a sensor input schema (e.g. information on computer screen), a motor schema (e.g. how to open a valve to fill a tank), and a sensor output schema (e.g. to see whether the tank fills). An action schema is a realization of a so-called TOTE unit (Miller, Galanter, & Pribram, 1960) and includes an action sequence of Test (whether conditions are given), Operate (execute action), Test (whether expectation is met), and Exit (or continue, Dörner, & Güss, 2013, p. 304).

Acquiring a skill is the basis for a competent, expert, rapid and conscious performance (Anderson, 1982). For the acquisition of complex cognitive skills, an extensive learning phase is necessary (time and effort). For the adaptive transfer, the operators not only need to know "what" to do and "how" to do a task, but they also need to have an underlying understanding of the task, to know "why" things happen (Kimball & Holyoak, 2000). The understanding of the task can be acquired by information- and practice-based learning (Salas & Cannon-Bowers, 1997), which can take the form of simulator-based learning (Wexley & Latham, 2002). This type of learning is important for the acquisition and application of learned skills in a realistic setting, which facilitates learning transfer (Kluge, 2014; Wexley & Latham, 2002). Simulator-based learning can help to transfer the learned skills in a realistic setting with a very high number of identical elements (Thorndike, 1904; Salas et al., 2012).

In the present paper, it is assumed that complex cognitive skills in terms of knowing "what" "how" and "why" are acquired during initial training through information- and practice-based learning (Salas & Cannon-Bowers, 1997).

Determinants of temporal transfer

Since most of the time, automated control loops regulate the technical systems, fault-finding skills as well as system control skills may face long periods of non-use (Stammers, 1996; Kluge, Sauer, Burkolter, & Ritzmann, 2010). Furthermore, process control involves low-frequency tasks (e.g., start-up and shut-down procedures), which are also at risk of skill decrements and loss of the ability to recall an action schema (Dörner & Güss, 2013) due to non-use (Arthur, Bennett, Stanush, & McNelly, 1998). A meta-analysis of research on skill retention revealed that procedural skills in particular are very vulnerable to forgetting (Arthur et al., 1998). Temporal transfer is affected by achieving a high level of proceduralisation of skills through repeated practice of a task (Kluge et al., 2009). Farr (1987) and Arthur et al. (1998) pointed out that the degree of initial learning can be increased by rehearsal and repetition. This is supported by Merrill (2001) and by further research evidence provided by Foss, Fabiani, Mané and Donchin (1989), Kontogiannis and Shepherd (1999), Mattoon (1994), Morris and Rouse (1985), Hesketh (1997), and Hagman and Rose (1983), who concluded that repetitions are effective when applied both before and after task proficiency has been achieved. Similarly, Goldstein and Ford (2002) referred to automaticity of task completion as a powerful means to maintain performance over extended lay-off periods. Research has found that satisfactory skill retention can be achieved even after considerable lay-off periods if appropriate training methods are used. However, differences in the effectiveness of different methods for temporal transfer have also been shown (e.g. Kluge et al., 2009; Kluge & Frank, 2014).

Determinants of adaptive transfer

Adaptive transfer can be explained by analogy transfer (Gentner, 1983), which means that analogical content, e.g. a complex skill and action schema (Dörner & Güss, 2013), has to be recalled from memory, aligned and mapped to the target scenario (Gentner, Holyoak, & Kokinov, 2001). A learned complex skill cannot be applied 1:1 but needs to be adapted to fit the particular purpose for which no schema exists. A selection of learned skills that need to be adapted is recalled from memory in order to compare their usefulness in the new context. Recall can be guided by structural similarity ("Do I know a similar context? e.g. from process control? Can I use my skills learned in a different plant?") or by structural similarity ("Do I remember a solution that I once applied (independent of the context), which might be useful here?"). Empirical findings suggest that recall of analogical content is supported by surface similarity of the target scenario (Catrambone, 2002), and the alignment and mapping of learned content for a new target scenario is supported by structural similarity (Gentner, Rattermann, & Forbus, 1993). Past research has shown that methodological and person-related variables determine adaptive transfer. Methodological factors such as teaching methods (e.g. case-based learning, comparing examples, discovering), degree of learning, learning strategy, similarity of transfer context and whether the transfer is informed or uninformed have been found to be important for acquiring the competence to handle adaptive transfer (Gentner, Loewenstein, & Thompson, 2003, 2004; Kimball & Holyoak, 2000). Person-related factors that can affect adaptive transfer are, for example, domain-specific knowledge, prior knowledge and task specific knowledge, problem-solving competence and general mental ability (Abele et al., 2012; Noke, 2005). As mentioned above, adaptive transfer can be described similarly to complex problem solving (Wüstenberg et al., 2012): Complex problem solving means the successful interaction with dynamic task environments and a successful exploration and gathering of information to reveal the environments' regularities (Buchner, 1995). Considering the similarities between adaptive transfer and complex problem solving, some studies have shown an effect of general mental ability on complex problem solving, while others have not (e.g. Beckmann & Guthke, 1995; Wittmann & Hattrup, 2004). Moreover, results regarding the importance of general mental ability for solving new tasks have been inconsistent (Abele et al., 2012).

General mental ability can be described as the capacity "that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience" (Gottfredson, 1997, p. 13). In line with the modified model of primary mental abilities (Kersting, Althoff, & Jäger, 2008), general mental ability can be described as the combination of fluid and crystallized intelligence. Fluid intelligence is the given intelligence, which cannot be influenced by the environment, provides the basis for crystallized intelligence, and is necessary in order to learn new information and to solve new problems (Cattell, 1963; McGrew, 2009; Primi, Ferrão, & Almeida, 2010). Crystallized intelligence consists of knowledge and abilities that are learned during the lifetime, and also depends on cultural background (Cattell, 1963; Maltby, Day, & Macaskill, 2011). General mental ability is assumed to be an important prerequisite for learning, meaning that high general mental ability alone will not qualify operators to complete tasks or solve a problem. Rather, operators must also acquire complex cognitive skills that enable them to handle the system's processes, procedures and objectives, and learn, for instance, how to time actions and allocate attention (Fischer & Neubert, 2015). For this reason, operators first have to acquire skills on what to do and how to do the task, as well as to understand the underlying mechanisms of the task in order to solve an adaptive transfer. A meta-analysis by Colquitt, LePine, and Noe (Colquitt, LePine, & Noe, 2000) showed that general mental ability predicts learning and learning transfer to a medium extent. In summary, various studies have found that general mental ability predicts learning and learning transfer of complex skills (Blume, Ford, Baldwin, & Huang, 2010; Burke & Hutchins, 2007; Day, Arthur, & Gettman, 2001; Day et al., 2013; Hülsheger et al., 2007; Rosander, Bäckström, & Sternberg, 2011; Schmidt & Hunter, 2004).

As the transfer of tasks is also determined by the acquisition of knowledge and the retention of such knowledge, it therefore depends on memory (Kimball & Holyoak, 2000). Additionally, the retrieval of analogical content is the starting point for modifying learned content for new situations (Gentner et al., 1993). Thus, memory might also affect adaptive transfer. Memory is defined as the ability to memorise and reproduce information and associations that were learned a short time ago (Kersting et al., 2008). It is the ability to store information in the short and medium term as well as to recall it (Jäger, Süß, & Beauducel, 1997; Kersting et al., 2008; Thurstone, 1938). Memory can be described as one component of fluid intelligence referring to the modified model of primary mental abilities (Kersting et al., 2008). It is divided into three content abilities: verbal memorisation, numerical memorisation and figural memorisation. Verbal memorisation describes, e.g., communication skills; numerical memorisation describes, e.g., mathematical skills; and figural memorisation describes, e.g., spatial skills. With regard to the objectives of this paper, it is assumed that, although it is likely that many of the basic mechanisms of memory are common across individuals, the encoding and organisation of information varies as a function of individuals' memory (Beauducel & Kersting, 2002). Moreover, despite the fact that, as early as 1938, Thurstone called for memory to be exhaustively studied due to its significance for education and training, research in this area is still lacking.

The present study further analyses the relation between general mental ability, memory and solving the adaptive transfer in a process control task. It is examined whether participants who are trained in an information- and practice-based manner are able to solve an adaptive transfer, and whether their performance depends on general mental ability and/or memory. Information-based learning focuses on learning knowledge transfer, whereas practice-based learning focuses on learning by experience (Salas & Cannon-Bowers, 1997).

The effect of general mental ability has been widely analysed in the context of skill acquisition (e.g. Ackerman, 1992; Burkolter, Kluge, Sauer, & Ritzmann, 2009; Matthews, Davies, Westerman, & Stammers, 2000). However, only a few studies have investigated the effect of general mental ability on temporal transfer and adaptive transfer in the context of complex cognitive skills in industrial tasks (e.g. Day et al., 2013; Gonzalez et al., 2005). So far, our own studies have shown that general mental ability and memory influence temporal transfer (Frank & Kluge, 2015; Kluge et al., 2015). Based on the theoretical outline given above, we assume that persons with higher general mental ability are better able to perform the adaptive transfer because of their greater ability to process and understand complex ideas and to learn from experience. To investigate the impact of general mental ability on complex cognitive skills, the following hypothesis is formulated:

H1: General mental ability positively affects adaptive transfer.

As it is important to be able to use analogical content as a starting point in new situations (Kimball & Holyoak, 2000), the recall of the memorised learning environment, learning interface and the learned skills is expected to affect adaptive transfer. Therefore, the single effect of memory is analysed to ascertain whether memory alone might affect adaptive transfer. Accordingly, we propose the following hypothesis for the effect of memory on adaptive transfer:

H2: Memory positively affects adaptive transfer.

Method

Sample

The results of the present sample originate from a larger DFG-funded project (DFG KL2207/3-3) on skill retention and its influencing factors, with a particular focus on refresher training methods and their interaction with person-related variables. The overall sample comprised 200 participants across 10 different experimental conditions (4 refresher interventions, 1 control group x 2 types of sequences; see Appendix A). The two groups without any refresher training methods are analysed to investigate the effect of general mental ability and memory on adaptive transfer in the present study. The study was conducted from October 2014 to December 2015. All participants were randomly assigned to the different experimental conditions.

From October 2014 to December 2015, 40 engineering students (12 female) were part of the described subsample of the study. Seven participants were excluded based on a predefined selection criterion (the participants were requested to produce >= 200 litres of purified gas). The participants were recruited by postings on social networking sites and flyers handed out to engineering students. To ensure technical understanding, which was required for the technical task, only students from faculties of engineering were recruited. Participants received 25 Euros for taking part. The study was approved by the local ethics committee. Participants were informed about the purpose of the study and told that they could discontinue participation at any time (in terms of informed consent). All participants were novices in learning the process control task used in the study.

The process control task

The complex cognitive skill in the present study was acquired in a simulated process control task: The participants had to learn the content of the particular start-up procedure (SOP) and how to interact with the interface in order to operate the microworld Waste Water Treatment Simulation (WaTrSim, Figure 1). WaTrSim represents a typical task of a so-called control room operator in process industries such as chemical plants, refineries, steel production etc, in which operators work in control rooms and are required to observe, monitor, control, and optimize the process variables with the help of synoptic diagrams (Kluge, Nazir & Manca, 2014). Control room operators control material and energy flows, which are made to interact with and transform each other (Kluge, 2014). By means of physical or chemical transformation, the "process control industry" incorporates the continuous and batch processing of materials and energy in their operations (Moray, 1997). "Examples include the generation of electricity in conventional fuel and nuclear power plants, the separation of petroleum by fractional distillation in refineries into gas, gasoline, oil, and residue, hot strip rolling in steel production, chemical pulping in the production of paper; pasteurization of milk, and high-pressure synthesis of ammonia" (Woods, Obrien & Hanes 1987, p. 1726).

WaTrSim represents a complex technical system, as it includes:

Couplings and interconnections (Kluge, 2008; Moray, 1997; Vicente, 2007; Wickens & Hollands, 2000), which require the operator to simultaneously process the interplay of cross-coupled variables in order to either assess a process state or predict the dynamic evolution of the plant.

Dynamic effects (Kluge, 2008; Vicente, 1999; Walker, Stanton, Salmon, Jenkins, & Rafferty, 2010), which require the operator to mentally process and envisage the change rates of cross-coupled variables and to develop sensitivity for the right timing of decisions in order to be successful (Kluge, 2014).

Non-transparency (Funke, 2010; Kluge, 2014; Vicente, 1999; Woods, Roth, Stubler, & Mumaw, 1990), which requires the operator to work with more or less abstract visual cues that need to be composed into a mental representation and compared with the operator's mental model (Kluge, 2014).

Multiple or conflicting goals (Brehmer & Dörner, 1993; Funke, 2010; Kluge, 2008; Reason, 2008; Verschuur, Hudson, & Parker, 1996; Wickens & Hollands, 2000), which require the operator either to balance management intentions or to decide on priorities in the case of goal conflicts in the decision-making process, e.g. which course of action to take (Kluge, 2014).

In WaTrSim, the operator's task is to separate waste water into fresh water and gas by starting up, controlling and monitoring the plant. WaTrSim was developed by colleagues from the Technical University Dresden who are specialised in complex technical systems and automation (Burkolter, Kluge, German & Grauel, 2009). The operation goal is to maximize the amount of purified water and gas and to minimize the amount of waste water. This goal is achieved by considering the timing of actions and following the start-up procedure. The type of start-up procedure is an independent variable in the present study. A demonstration of the procedure can be found here: http://www.aow.ruhr-uni-bochum.de/fue/gazeguiding.html.de

The operation of WaTrSim includes the start-up of the plant in 13 steps in the fixed sequence and 18 steps in the contingent sequence (see Appendix A). A start-up procedure is assumed to be a non-routine situation that requires skill retention (Wickens & Hollands, 2000). Due to safety reasons in order to avoid a deflagration, the start-up procedure is predefined. Usually, the start-up process of a large chemical process plant takes several hours, up to days or even weeks. In WaTrSim, processes are speeded up, with one simulation step equalling one second. The operator receives direct feedback of his/her actions. The operator's actions are executed on 6 valves, 4 tanks and a heating system in the fixed sequence (see Figure 1) and 9 valves and 2 heating systems in the contingent sequence (Figure 1 and Appendix 1). The handling of WaTrSim can usually be learned within 2 hours. WaTrSim has been used for experimental studies since 2009 in different versions, dependent on the purpose of the respective study (e.g. Burkolter et al., 2009; Kluge, Burkolter & Frank, 2012; Kluge & Frank. 2014; Kluge, Frank & Miebach, 2014; von der Heyde, Brandhorst & Kluge, 2015a/b).

The adaptive transfer task

Two weeks after the initial training, the participants had to perform a) the temporal transfer of the initially learned task and b) the adaptive transfer task. The adaptive transfer task consisted of controlling and adjusting the plant operation in response to an unknown technical fault that occurred: The participants were told that due to a technical fault, two tank trunks can only deliver waste water with a volume of 900 l/h in-

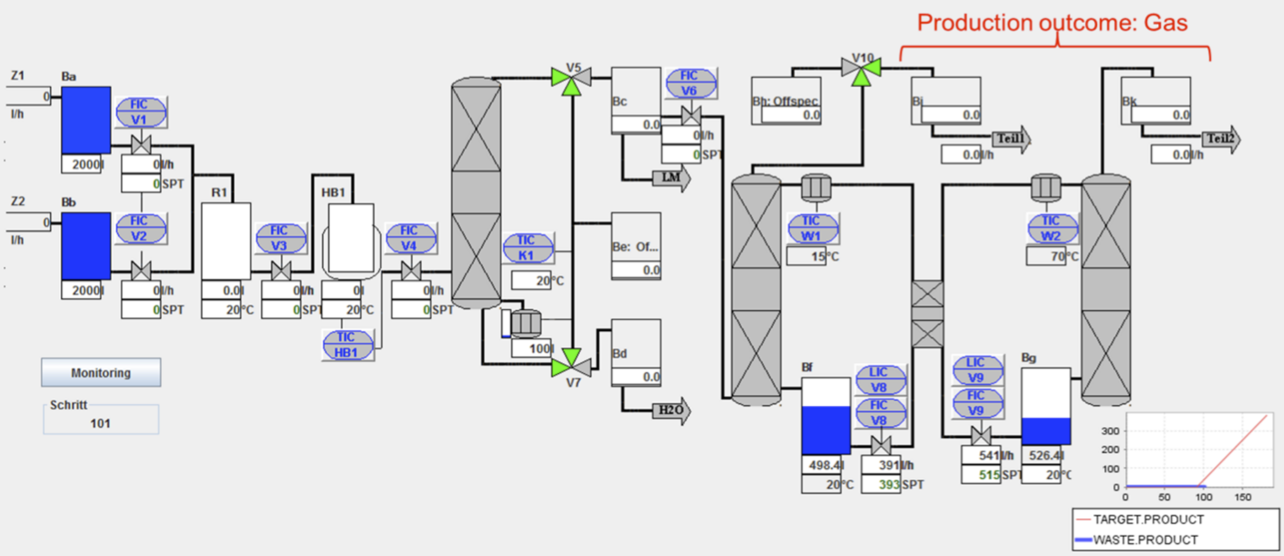

Figure 1. WaTrSim interface. The production outcome tanks for purified gas are labelled in red.

stead of 1200 l/h. Additionally, the tank trunks cannot deliver waste water at inflow Z1 until the simulation step 240, because of reconstructions of inflow Z1. The task took 480 seconds of operating WaTrSim and participants controlled the plant with already filled tanks and a broken inflow. Adaptive transfer was measured by production outcome. An example solution procedure is given in Appendix B.

Research design

A within-subjects design was implemented. The performance of one group was analysed at two measurement times (week 1: initial training and week 3: transfer assessment).

Procedure

The participants attended the initial training (week 1) and two weeks later took part in the transfer assessment (operation without help; week 3; Figure 2).

Initial Training: In week 1, the participants were trained in an information- and practice-based manner on how to start up the plant using the start-up procedure. This initial training lasted for 120 minutes. First, the participants were welcomed and introduced to WaTrSim. After completing tests concerning variables measuring individual differences relevant for the study (general mental ability and memory) and prior knowledge, participants explored and familiarised themselves with the simulation twice. They were then given information and instructions about the start-up procedure and practiced performing the 13-step start-up procedure (see Appendix A) four times. During these first four trials, participants were allowed to use and consult the manual. Following this, they had to perform the start-up procedure four times without the manual and were required to produce 200 litres of purified gas at least once. The best trial of this series was used as the reference level of skill mastery after training. The amount of purified gas was used as selection criterion: The participants were requested to produce >= 200 litres of purified gas.

Transfer assessment: Two weeks after the initial training, the transfer assessment took place, which lasted for approximately 30 minutes (week 3). After the participants had been welcomed, they were asked to start up the plant *up* to five times without help (temporal transfer) and were then asked to operate a new task (adaptive transfer).

Variables and Measures

Independent variables: General mental ability and memory

General mental ability: General mental ability was measured at the beginning of the initial training with a German version of the Wonderlic Personnel Test (Wonderlic, 2002). Participants answered 50 items in twelve minutes, including analogies, analysis of geometric figures, logic tasks, mathematical tasks, similarities or word definitions like "A boy is five years old and his sister is twice his age. When the boy is eight, how old will his sister be?" Correct answers were summed up (range: 0 to 50; α=.93; Wonderlic, 2002). The average score was 26.52 (SD=5.11), which is comparable to scores from other German-speaking studies (cf. Blickle & Kramer, 2012).

Memory: Memory was measured with the Wilde Intelligence Test-2, consisting of verbal, numerical and figural information (Kersting et al., 2008). The participants had to memorise the presented information for four minutes. After a disruption phase of 17 minutes, they answered 21 reproduction tasks of the memorised information, choosing one of six response options (range: 0 to 21; α=.78; Kersting et al., 2008).

Sequence: Participants executed either the fixed- or the contingent-sequence start-up procedure. The operation included the start-up procedure of the plant as a fixed sequence comprising 13 steps (described in Appendix A) or a contingent sequence with 13 steps and five consecutive steps. Performing the WaTrSim

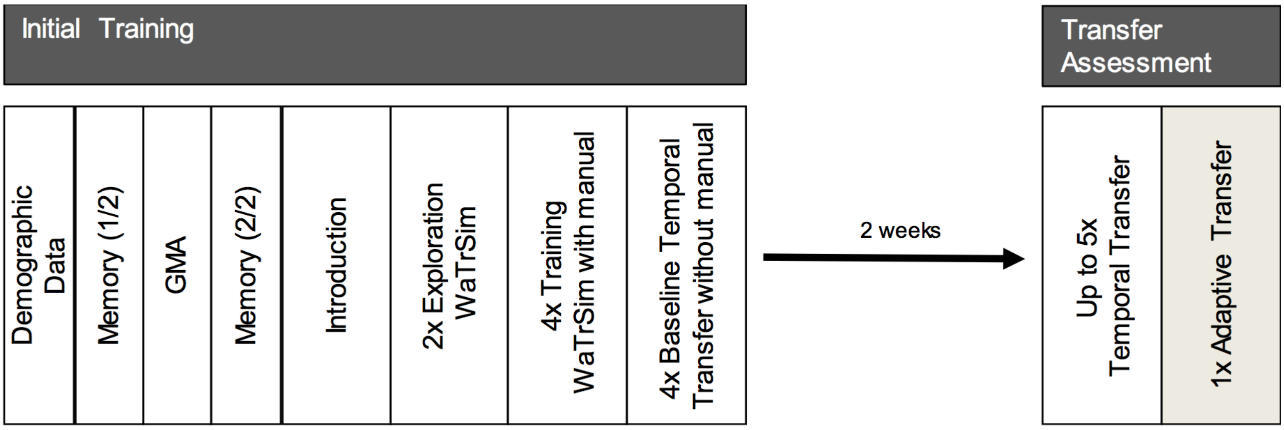

Figure 2. Procedure of the study.

start-up procedure with a fixed sequence correctly and in a timely manner led to a production outcome of a minimum of 200 litres of purified gas. The start-up time was max. 180 seconds. The operation of the contingent sequence included the start-up procedure of the plant as a contingent-sequence task comprising 13 steps and a subsequent five steps for each condition. The subsequent five steps had to be executed depending on the conditions: heating $W1>15°C$ or heating $W2<70°C$. After one of the conditions (step 1 of 5) had occurred, the correct following four steps had to be executed (described in Appendix A). Performing the WaTrSim start-up procedure correctly and in a timely manner led to a production outcome of a minimum of 200 litres of purified gas. The start-up time was max. 240 seconds due to the fact that the start-up procedure consisted of five additional steps. Compared to the fixed sequence, when executing the contingent sequence, the correct collection, selection and interpretation of information is critical in order to correctly understand the status of the plant. Based on the correctly inferred status of the plant (the "if" condition in the present study, whether $W1 > 15°C$ or $> 70°C$), the operator decides ("then") which steps of the procedures need to be applied – a or b. This process requires selective attention (Wickens & McCarley, 2008) and visual scanning of the interface in order to gather the required data from the screen.

Dependent variables: Adaptive transfer

Adaptive transfer: The adaptive transfer was measured by the produced amount of purified gas at the transfer assessment (week 3).

Control variables: Temporal transfer and prior knowledge

Temporal transfer: The baseline temporal transfer was measured by the produced amount of purified gas at initial training (week 1) and transfer assessment (week 3), which was logged by the simulation program. To ensure that all participants began with a similar set of skills, they were required to produce a minimum of >= 200 litres at initial training. The best trial of initial training and the first trial of transfer assessment were used for calculations. The best trial was used as a reference level for the best performance shown during initial training because participants were required to produce 200 litres at least once, and the first trial of transfer was used to assess participants' skill level after two weeks of not using the skill as this would be necessary, for example, after a real-world shut down.

Prior knowledge: As previous studies have shown an effect of domain or task knowledge on solving new problems (Abele et al., 2012; Kimball & Holyoak, 2000), domain knowledge was assessed with a prior knowledge test. This test included seven questions about wastewater and general technical knowledge, and assessed knowledge about wastewater treatment and basic chemical understanding (range: 0 to 7; α=.65).

Results

To ensure that all participants were able to operate the task correctly and started under the same conditions, only participants with a production outcome of $\geq$ 200 litres (selection criterion) during initial training were included in the calculations. Thirty-three of the 40 participants were included in the following calculations. Descriptive statistics are given in Table 1. To ensure that prior knowledge had no effect on adaptive transfer, a Spearman correlation was calculated, with r=.261, p=.142 (see Table 1).

Hypothesis-testing

A Spearman correlation between general mental ability, memory and adaptive transfer was calculated to test the hypotheses. The results are shown in Table 1. The correlations showed a significant effect of general mental ability (r=.385, p=.027) on adaptive transfer but no effect of memory (r=.142, p=.432). Hypothesis 1, regarding the correlation of general mental ability and adaptive transfer, was therefore supported, but Hypothesis 2, regarding the correlation of memory and adaptive transfer, cannot be accepted. Additionally, a significant correlation between adaptive transfer and temporal transfer at week 2 was found (r=.350, p=.046).

Table 1. Descriptive statistics and correlations

	Statistics	Corrrelations						
		1	2	3	4	5	6	7
1 Sex	10 female 23 male	-						
2 Age	22.36 (3.06, 18-30)	.186	-					
3 Prior knowledge	5.42 (1.37, 2-7)	.189	.342	-				
4 Baseline for temporal transfer (week 1; min. 200 litres)	383.48 (96.17, 236-607.96)	.232	.113	-.055	-			
5 Temporal transfer (week 3)	55.95 (98.95, 0-299.93)	.043	.074	.133	-.031	-		
6 General mental ability (0-50)	26.52 (5.11, 18-36)	.108	.241	.385*	-.004	.219	-	
7 Memory	(0-21) 14.18 (2.88, 6-20)	-.028	.194	.408*	.042	-.031	.536**	-
8 Adaptive Transfer (week 3)	337.95 (291.38, 0-948)	.098	.229	.261	.228	.350*	.385*	.142

In the following, the sequence of start-up procedure (fixed or contingent sequence) was considered as independent variable to analyse whether general mental ability had an effect on adaptive transfer as covariate. An ANCOVA with dependent variable adaptive transfer, independent variable sequence (fixed or contingent sequence) and covariate general mental ability was calculated. The calculations showed a significant main effect of covariate general mental ability on adaptive transfer (F(1,32)=6.68, p=.015, n_p^2=.18). No effect of type of sequence was found (F(1,32)=1.19, p=.284, n_p^2=.04). This indicates the effect of general mental ability but no effect of sequence.

Moreover, when analysing the effect of memory on adaptive transfer, no significant effect of memory or type of sequence was found (memory: F(1,32)=1.34, p=.403, n_p^2=.77; sequence: (F(1,32)=1.33, p=.309, n_p^2=.24).

Discussion

The present study showed that general mental ability and adaptive transfer correlated positively, with a medium effect size. However, no effect of memory on adaptive transfer was found. For further understanding and to ensure that the different learning conditions did not cause any biases, it was analysed whether the task itself had an effect on the presented results, but no effect of task was found. This leads to the conclusion that the performance in an adaptive transfer task correlates with general mental ability regardless of the initially learned task. The correlation between general mental ability and adaptive transfer provides a slight indication that participants with higher general mental ability levels have a higher chance of solving complex problems. The results on the effect of general mental ability are in line with previous research demonstrating a relation of general mental ability with performance, complex problem solving or temporal transfer (Buchner, 1995; Burke & Hutchins, 2007; Cattell, 1987; Day et al., 2001; Gentner et al., 1993; Hülsheger et al., 2007). The present findings are also supported by other research using a similar process control task for temporal transfer (Frank & Kluge, submitted).

Nevertheless, it was also found that the cognitive ability of memory is not required for adaptive transfer. This can be explained by the fact that to solve a complex task, it is not sufficient to remember how a once learned task has to be performed; rather, it also seems to be necessary to be able to understand the new task and combine and develop new strategies. This is also supported by previous studies on memory, which found memory to be an important factor for temporal transfer of complex tasks (Frank & Kluge, 2015; Kluge et al., 2015). However, as the present study shows, memory alone might not be as important as general mental ability for adaptive transfer. Thus, memory seems to be more important for temporal transfer than for adaptive transfer.

The results showed a substantial correlation between general mental ability and memory and also a correlation between temporal transfer at week 3 and adaptive transfer. This indicates that the performance before the adaptive transfer influenced the performance at the adaptive transfer. The low temporal transfer at week 3 leads to the conclusion that if participants had shown a higher temporal transfer at week 3, they could have operated the adaptive transfer even better than in the present study. This can be attributed to the fact that with a better performance in temporal transfer, the skill is retrained, and the task, operation and underlying procedures might be better understood by the participants (Beckmann & Guthke, 1995). As past studies have shown inconsistent results regarding the effect of general mental ability on complex problem solving, and due to the small sample size, these results should be replicated in future studies with a larger number of participants and a wide range of tasks to reproduce the effect (Beckmann & Guthke, 1995; Wittmann & Hattrup, 2004). It would also be interesting to analyse sub-processes of the task in order to investigate the effects of rule identification, rule knowledge and rule application, as components of complex problem solving, on adaptive transfer.

To ensure that all participants had a similar background and similar previous knowledge, the sample in the present study comprised only engineering students. Moreover, only participants with a minimum production outcome were included. This might have affected the variance of the study sample, but on the other hand, it was necessary to be certain that all participants had the same skill level before performing the adaptive transfer task. The effect of prior knowledge was assessed and showed no effect on adaptive transfer, which is in line with previous research (Kluge & Frank, 2014; Kluge, Frank, & Miebach, 2014). However, future studies could also control for task-specific knowledge. As past studies found effects of domain- or task-specific knowledge on problem-solving skills (Abele et al., 2012), the present results would benefit from an analysis of the moderating effect of such concepts. Additionally, the used skill acquisition learning method was designed to teach the temporal transfer of the complex task. Future studies could apply a more strategic learning method with a focus on a deeper understanding of the task and the use of complex problem solving, which could help to gain more specific domain knowledge (Anderson, 2005; Kimball & Holyoak, 2000). As past studies showed an impact of general mental ability on learning and of learning on performance, it might be interesting to analyse the moderation or mediation effects of learning strategies on the relationship between mental ability and adaptive transfer.

In summary, the present study gives first indications that in a complex task work environment, the handling and operation of an adaptive transfer can be affected by the employees' general mental ability. The findings also indicate that memory is not required for solving complex problems. However, in order to take into account variables other than general mental ability, future studies could analyse the potential of different learning strategies to counteract general mental ability effects on adaptive transfer.

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Appendix

Appendix A: Procedures Study 1 and Study 2

For further understanding, see also: http://www.aow.ruhr-uni-bochum.de/fue/gazeguiding.html.de

Step	**Study 1** Fixed-sequence task Start-up procedure: 13 steps
	Description
1	LIC V9: Flow rate 500 l/h
2	V2 deactivate follower control
3	Valve V1: Flow rate 500 l/h
4	Wait until R1 > 200 l
5	Valve V2: Flow rate 500 l/h
6	Wait until R1 > 400 l
7	Valve V3: Flow rate 1000 l/h
8	Wait until HB1 > 100 l
9	Activate heating HB1
10	Wait until HB1 > 60°C
11	Activate column K1
12	Valve V4: Flow rate 1000 l/h
13	Valve V6: Flow rate 400 l/h

Step	**Study 2** Contingent-sequence task Start-up procedure: 13 steps and 2x5 steps	
	Description	
1	LIC V9: Flow rate 500 l/h	
2	V2 deactivate follower control	
3	Valve V1: Flow rate 500 l/h	
4	Wait until R1 > 200 l	
5	Valve V2: Flow rate 500 l/h	
6	Wait until R1 > 400 l	
7	Valve V3: Flow rate 1000 l/h	
8	Wait until HB1 > 100 l	
9	Activate heating HB1	
10	Wait until HB1 > 60°C	
11	Activate column K1	
12	Valve V4: Flow rate 1000 l/h	
13	Valve V6: Flow rate 400 l/h	
14	W1 > 15°C	**OR** W2 > 70°C
15	LIC V8 deactivate	LIC V8 deactivate
16	LIC V9 700 l/h	LIC V9 600 l/h
17	LIC V8 500 l/h	LIC V8 400 l/h
18	Heating W1 15°C	Heating W2 70°C

Appendix B: Adaptive transfer example solution procedure

Appendix B shows one possible strategy to solve the adaptive task after two weeks. However, this procedure is only one of many possible solutions on how to handle the adaptive transfer.

Adaptive Transfer **Example Solution Procedure**	
Step	**Description**
1	LIC V9: Flow rate 500 l/h
2	V2 deactivate follower control
3	Valve V3: Flow rate 500 l/h
4	Activate heating HB1
5	Activate column K1
6	Valve V4: Flow rate 500 l/h
7	Valve V2: Flow rate 700 l/h
8	Valve V3: Flow rate 700 l/h
9	Valve V4: Flow rate 700 l/h
10	*Simulation step 240: Wait until BA > 400 l*
11	Valve V1: Flow rate 600 l/h
12	Valve V3: Flow rate 1400 l/h
13	Valve V4: Flow rate 1080 l/h
14	Valve V4: Flow rate 700 l/h
15	Valve V6: Flow rate 400 l/h