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SHARED MENTAL MODELS AS MODERATORS OF TEAM PROCESS-PERFORMANCE RELATIONSHIPS

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The effects of shared mental models on the relationship between episodic team behavioral processes and performance were investigated, while teams were using an experimentally stimulated construction project planning program. The results indicated that episodic team processes made positive contributions to the team performance. Furthermore, a hierarchical linear regression indicated that the convergence of shared teamwork mental models moderated the effects of team processes on team performance. Specifically, the positive impact of team processes on performance was found to be improved for those teams who shared more similar teamwork mental models than for teams who hold fewer similar teamwork mental models. Potential implications and relevant impacts on future research are discussed.

Keywords: team processes, shared mental models, team performance.

Although the input-process-output (IPO) framework (Hackman, 1987; McGrath, 1984; Steiner, 1972) has had a powerful influence over recent empirical research on team performance, this model fails to show the emerging consensus about teams as complex adaptive systems. Therefore, Ilgen, Hollenbeck, Johnson, and Jundt (2005) raised the input-mediator-output-input (IMOI) model, which takes multiple mediators between team inputs and outcomes and their interactions into account. In comparison with the IPO models, the IMOI model substituted "M"

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for "P" which reflects a broader range of variables. For example, the mediator (M) involves behavioral constructs such as planning and emotional constructs such as potency which have been organized in team processes (Marks, Mathieu, & Zaccaro, 2001), and cognitive constructs like shared mental models (SMMs), which are considered to be emergent states. Moreover, the model with the additional "I" factor invokes the notion of cyclical causal feedback as reflecting the interactive and dynamic features of work teams. The lack of the hyphen between letters signifies that the causal linkages may not be linear or additive, but rather nonlinear or conditional.

It is well documented that team processes have a significant impact on team effectiveness (Guzzo & Dickson, 1996; Ilgen et al., 2005; Marks et al., 2001). Team processes have been divided into the following three categories: (1) transition processes, which are focused on interpreting feedback and environmental information, setting goals, and planning future action; (2) action processes, which are related to actions involved in the execution of task work; and (3) interpersonal processes, which are related to the sociopsychological aspects of teamwork.

From another aspect, the SMMs have long been considered to play vital roles in team performance especially for those requiring intact corporation but lacking enough coordination time. As Cannon-Bowers and Salas (1993) suggested, *SMMs* are defined as *knowledge structures held by members of a team that enable them to form accurate explanations and expectations for the task, and, in turn, to coordinate their actions and adapt their behaviors to demands of the task and other team members* (p. 228). The SMMs explain how teams are able to cope with difficult and changing task conditions. Some researchers have proposed that four types of mental models coexist at any given time (Klimoski & Mohammed, 1994): equipment, task, interaction, and teammate. However, Mathieu, Goodwin, Heffner, Salas, and Cannon-Bowers (2000) argued that these four types of mental models actually reflect two broad content domains, namely task-related features of situations (e.g., equipment and task model), and team-related aspects of situations (e.g., the interaction and teammate model). McIntyre and Salas (1995) justified the theory that team behaviors could be categorized into two diverse tracks – taskwork track (labeled as the taskwork mental model) and teamwork track (labeled as the teamwork mental model). The SMMs provide an indication of the degree to how well team members' understandings of the task and interaction are shared. In previous literature, shared taskwork mental models have been assessed using similarity ratings of the relationships among critical task concepts (Marks, Sabella, Burke, & Zaccaro, 2002; Mathieu et al., 2000; Stout, Cannon-Bowers, Salas, & Milanovich, 1999). Shared teamwork mental models were assessed based on Webber's work (2002) which index the similarity of rank orderings of judges' target ratings. This method of assessment was also used by Smith-Jentsch, Mathieu, and Kraiger (2005).

SMMs are thought to be emergent states (Marks et al., 2001); controversies exist as to whether SMMs interact with inputs and impose on process variables, or they interact with process variables and impose on outputs. According to the former view, elaborate planning prior to the mission would enhance or encourage team interaction, and this effect can be strengthened by SMMs among teammates. For example, Dyer (1984) found that team performance was improved when using teams with different levels of cooperating experience. According to the latter view, the SMMs are viewed in terms of cognitive constructs, which form and play vital roles. While in mission strategy adjustment, team coordination, and backup behaviors (Porter, 2005) were found to contribute to team performance, other similar mental models could facilitate the effect. For instance, with similar taskwork mental models, team members do not need to waste time finding out whom to report to, whom to query, or where to obtain resources. This means that team interaction processes are directly converted to outcomes, avoiding detours once teamwork mental models are formed.

Although numerous researchers have investigated how team processes and SMMs impact team performance, there are several limitations in these studies. Firstly, SMMs are measured in a static manner (Banks & Millward, 2007). In fact, one of most general (trait-like) attributes of SMMs relates to work teams as complex and multidimensional systems which function over time. Hence, in this study we remeasured the variables at three different time points. Secondly, the IPO model ensured heuristic elimination of possible temporal factors and did not take into account the interaction between emergent states of SMMs and team processes. In this study, we investigated these relationships based on the IMOI model. Finally, it should be noted that process variables are multiple and it is neither practical nor necessary to measure all of the dimensions associated with them. Following the suggestion of a number of researchers (e.g., Marks et al., 2001), we concentrated only on superordinate categories of transition and action process with dimensions most relevant to our research content.

Therefore, we hypothesized that:

Hypothesis 1a: Team transition processes will relate positively to team performance.

Hypothesis 1b: Team action processes will relate positively to team performance.

It is known that SMMs play vital roles in team performance, and they can explain and predict the amount of participation of team members in a given task (Miles & Kivlighan, 2008) and their performance (Müller, Herbig, & Petrovic, 2009). However, few researchers have specifically examined how the two types of mental models interact with other variables or mediators to impact on team performance. Contrary to the ample research on the direct effects of SMMs on team processes and performance, some researchers have recently begun to explore the moderating role of this team cognitive construct in process-outcome relationships. For example, Bonito (2004) showed that similarity among team members' mental models moderated the relationship between team members' knowledge level and substantive participation on the team's task. When team members held more similar mental models, the amount of knowledge team members held mattered less in determining how much team members participated than when team members' mental models held a lesser degree of similarity. Extending the above reviewed results, we expected that SMMs would improve the process-performance relationship. That is, the positive impact of team processes on performance would be improved to some extent for those teams that share more similar SMMs than for those with less similar SMMs.

Therefore, we hypothesized that:

Hypothesis 2a: The relationship between team processes (including transition and action processes) and performance will be moderated by shared taskwork mental models so that the relationship will be more positive for teams with more similar shared taskwork mental models.

Hypothesis 2b: The relationship between team processes (including transition and action processes) and performance will be moderated by shared teamwork mental models so that the relationship will be more positive for teams with more similar shared teamwork mental models.

METHOD

PARTICIPANTS

A total of 150 young healthy undergraduate students aged between 17 and 24 (mean 21.3 years) from two universities in the north of China participated in this study. They formed 50 three-person teams: 21 teams were composed of three male members, 27 teams were composed of three female members, and the remaining two teams comprised female and male members. All participants received a small sum of money as payment for their participation.

TASK APPARATUS

Teams were instructed to complete a simulated construction project planning program. Within each team, the three members acted as either a project manager (PJM), procurement manager (PCM), or human resource manager (HRM). Everyone contributed unique information and strategies for decision making. The mission of teams was to make an optimized construction plan, and then execute it and modify it according to circumstances within a time limit and using the lowest cost. Members of each team were required to cooperate and integrate their suggestions in order to optimize the decision. Team members were interdependent and inter-restricted. For example, the people hired by the HRM needed to use all the materials in specific subprojects, but the amount of available materials was set by the PCM. Similarly, the working load set by the HRM was to be kept in accordance with the project property which was set by the PJM. In addition to having the materials stocked in advance by the PCM, the team also needed to have information about the entire project quantities from the PJM in order to avoid overstock and waste of cost. The simulated task was characterized by interdependent roles, information asymmetry, limited time, a common team goal, and role specialization.

PROCEDURES

The participants were seated triangularly around three computers and communicated via microphones. After providing demographic information and completing questionnaires about their past experiences with the program used in this study, the role, and their partners, they were guided independently through a structured multimedia training course. The demonstration was used to ensure the participants received all relevant information. They then completed a practice session. After a period, they were asked to complete measures of SMMs including taskwork mental model and teamwork mental model. Upon finishing the demonstration and all measurements, they began the formal mission sessions. At the end of the experiment, team members were asked to rate the SMMs a second time. The whole experiment process was videotaped and rated by two subject matter experts (SMEs).

MEASUREMENTS

Shared taskwork mental models The shared taskwork mental models were assessed using individual ratings of relatedness among critical task concepts. The SMEs conducted a comprehensive team task analysis for each of the team positions and then identified ten task-related concepts across the roles that were critical to team success, including amount of labor, amount of materials, labor market price, material market price, optimal weather conditions, and so on. Participants were provided with a 9-point Likert scale that listed two concepts ranging from 1 (*strongly unrelated*) to 9 (*strongly related*). They were asked to rate the relatedness of each pair. According to the procedure used by Kraiger and Wenzel (1997), these data were entered into the Pathfinder computer program (Schwarz, 1994), which produced a similarity index (the “C” index), reflecting the overlap among each pair of members’ similarity matrices on a scale from 0 (*no overlap*) to 1 (*complete overlap*). These three C values (one for each pair of teammates) were then averaged to form the index of shared taskwork mental models convergence.

Shared teamwork mental models The shared teamwork mental models were assessed in a manner similar to that used by Webber (2002). Klimoski and Mohammed (1994) stated that “investigators interested in making use of the construct [team mental models] must be prepared to expend effort to understand critical features of the setting for the team behavior of interest” (p. 354). Accordingly, we relied strictly on a detailed analysis of the coordination requirements in a project environment when we constructed our mental model measures. The previous analysis suggested that, for many situations, there seemed to be multiple potential and effective task strategies in terms of team interaction behaviors. However, teammates did not necessarily agree with each other on the relative efficacy of each behavior order under specific conditions. On this basis, we reasoned that it was important for team members to agree on which strategy would be best to try first, second, and so forth. Thus, we considered having participants rank order of the potential strategies. The event used and the response strategies presented were developed on the basis of a pilot study and structured interviews with SMEs. The shared teamwork mental models were indexed using Kendall’s concordance coefficient, Fisher Z transformation, and average correlation.

Team processes Team processes were videotaped and rated twice by highly trained SMEs: firstly, the transition process was rated in the practice session; secondly, both transition and action processes were rated in the mission session. The SMEs rated the quality of team processes on the transition and action categories and five dimensions using the Behaviorally Anchored Rating Scale (BARS; Bernardin, LaShells, Smith, & Alvares, 1976). The five dimensions included mission analysis (Mathieu & Rapp, 2009), strategy formulation (Chou & Yeh, 2007) and planning (Woolley, Gerbasi, Chabris, Kosslyn, & Hackman, 2008), process monitoring, team monitoring, and backup behaviors and coordination, which were delineated by Marks et al. (2001). Using the BARS, the extent to which the teams effectively executed the two transition processes and three action processes was determined. The interrater reliability correlations ranged from .68 to .71 for each dimension. This indicated that data obtained had sufficient levels of interrater agreement and reliability. The 5-point Likert scale was developed according to the procedures designed by Smith and Kendall (1963) with the anchors on the scale ranging from 1 (*negative*) to 5 (*positive*). Each point was represented by three criteria, for example, shared all the information, mentioned the requirements, referred only to the responsibilities. These behaviors were collected and retranslated by an additional three SMEs. The consistency of the results found by three SMEs was .974, the effectiveness of incidents was 4.23 (SD = .71), and the reliability was .77.

Team performance Teams were given two goals to achieve: (a) minimize costs and (b) plan a 35 day mission within 30 minutes. Thus, teams who completed the mission plan were treated as valid samples. Five out of the 55 teams did not finish the job in the time given and were not included in the analysis; therefore,

TABLE 1
Means, Standard Deviations, and Correlations Among Variables

Variables	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Average team age	21.30	1.93	—													
2. PC experience[a]	38.88	18.03	.08	—												
3. Experience with the program[b]	3.57	1.00	-.13	.20	—											
4. SAA[c]	4.51	0.73	-.09	-.17	.41**	—										
5. Friendship with teammates[d]	5.76	0.72	.05	.08	-.04	.10	—									
6. Transition process 1	2.76	0.84	.04	-.08	-.18	-.01	.16	—								
7. Taskwork MM 1	0.50	0.75	-.09	.24	.47**	.15	.12	-.09	—							
8. Teamwork MM 1	0.62	0.27	.05	.24	-.02	-.04	-.05	-.12	-.10	—						
9. Transition process 2	3.44	0.79	.16	-.08	.00	.10	.15	.75**	-.15	-.03	—					
10. Action process	3.32	0.71	.11	-.06	-.20	.03	.22	.68**	-.07	.00	.76**	—				
11. Team processes	3.38	0.70	.15	-.08	-.10	.07	.19	.76**	-.12	-.02	.94**	.93 *	—			
12. Taskwork MM 2	0.39	0.09	.21	-.00	.02	-.04	.19	.16	.22	-.01	.17	.19	.19	—		
13. Teamwork MM 2	0.63	0.30	-.20	-.02	-.14	.18	.25	.04	-.19	.48**	-.04	.12	.04	-.25	—	
14. Team performance	97398.60	11453.55	.08	-.25	-.18	-.19	.06	-.33**	-.00	-.03	-.37*	-.41**	-.42**	-.02	.11	—

Note: Analyses were conducted at the team level: $N = 50$.
* $p < .05$, ** $p < .01$
[a] Response to the question "When did you begin to use personal computers?" Participants' responses were translated into months. [b] Response to the question "In the past year, on average, how many hours per week have you spent playing team simulation games?" Participants responded on a scale ranging from 1 (*none at all*) to 7 (*very often*). [c] Response to the question "How is your scholastic assessment ability?" Participants responded on a scale ranging from 1 (*very poor*) to 7 (*very excellent*). [d] Average team member response to the following question: "Approximately how well do you know the people working with you today respectively?" Responses ranged from 1 (*not at all*) to 7 (*very familiar*). The scores were averaged to the team level analyses.

90% of teams were valid. The performance score was computed in terms of the sum of material cost, human resource cost, and some potential extra costs due to weather effects. Higher total costs reflected poorer team performance.

RESULTS

Descriptive Statistics

Table 1 shows correlations and descriptive statistics for all study variables. Correlations indicated that experience with the program, mean scholastic assessment ability, average team age, and team member friendship were not significantly correlated with key variables.

Analyses on Process-Performance Relationship

Hypothesis 1 was focused on the effect of in mission team processes on performance. An examination of the correlations in Table 1 illustrated that team processes (including practice and mission sessions) correlated significantly with ultimate performance. These results indicated that both team transition and team action processes indeed positively related to team performance as predicted in Hypothesis 1a and 1b.

Analyses on Moderation Effect of SMMs

In the next phase, we examined the extent to which SMMs moderated the effects of team processes on performance. Hierarchical regression analysis was conducted in which team processes and performance were predicted by main-effect terms (SMMs and transition processes) at step 1 and the interaction terms at step 2 (see Table 2).

Following recommendations made by Aiken and West (1991), team processes, SMMs, and performance were centered (by subtracting the mean from each score) and the interaction term was based on these centered scores. We regressed team performance on taskwork mental model (β = .09), team processes (β = -45), and their interaction ($\beta = .11$, $p = 0.46$). The results led us to conclude that there was no significant moderating effect of shared taskwork MMs on team process-performance relationships. Therefore hypothesis 2a was not supported. We then we regressed team performance on teamwork mental models, team processes, and their interaction. As can be seen in Table 2, the regression results indicated that both transition and action processes were positively related to team performance. More importantly, as we predicted in hypothesis 2b, there was indeed a significant interaction effect between team processes (either transition or action process) and teamwork mental models.

A further simple slopes analysis was conducted to analyze these interactions (Aiken & West, 1991). When teamwork mental models after the formal mission session were high, transition process in this session was marginally significantly related to performance (β = -.46, p < .10), whereas there was no significance when it was low (β = -.28) (see Figure 1).

TABLE 2
HIERARCHICAL REGRESSION ANALYSIS WITH TEAM PERFORMANCE AS DEPENDENT VARIABLE

Predictors	Team performance β	T	Predictors	Team performance β	T
Step 1			Step 1		
Transition process 2 (TP2)	-.37	-2.51	Action process 2 (AP2)	-.43**	-2.99**
Teamwork mental model 2 (TMM2)	.09	0.67	Teamwork mental model 2 (TMM2)	.17	1.16
$F(1, 40)$	3.46*		$F(1, 40)$	4.79*	
	.15			.19	
Adjusted	.11		Adjusted	.15	
Step 2	β	T	Step 2	β	T
Transition process 2	-.38	-2.67	Action process 2	-.47	-3.38
Teamwork mental model 2	.12	.82	Teamwork mental model 2	.14	1.04
TP2×TMM2	-.29*	-2.09	AP2×TMM2	-.29*	-2.14
$F(1, 39)$	3.95*		$F(1, 39)$	5.01**	
	.23			.28	
Adjusted	.17		Adjusted	.22	
Adjusted ΔR^2	.09		Adjusted ΔR^2	.09	

Note: N = 50; * p < .05; ** p < .01; *** p < .001

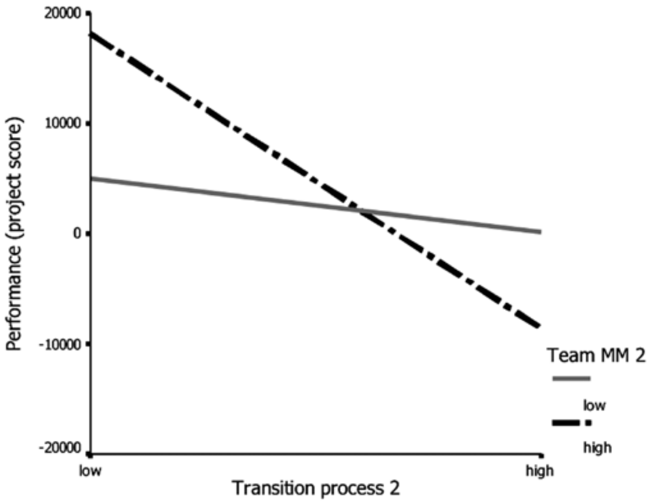

Figure 1. The relationship between transition process 2 and performance as a function of Teamwork Mental Model 2.

When teamwork mental models were high, action process was significantly related to performance (β = -.56, $p < .05$) but not when it was low (β = -.35; see Figure 2).

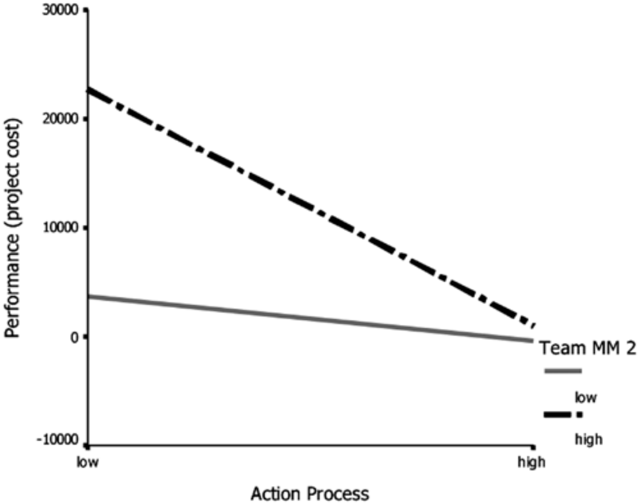

Figure 2. The relationship between action process and performance as a function of Teamwork Mental Model 2.

DISCUSSION

In the present study, we found firstly that team processes including team transitions and actions positively contributed to team performance. Secondly and also more importantly, we revealed that these contributions of team processes to team performance were significantly moderated by the convergence of shared teamwork mental models. For example, team performance was found to be improved more by team processes which relate to more similar teamwork mental models, whereas the planning and mission analyses did not compensate for the deficiency of team interaction with diverse teamwork mental models. These findings have some implications for research on the effects of teamwork mental models on the process-performance relation in the following ways. Firstly, this study supports the point of view that team processes contribute to performance. Secondly, this study extends the previous theories about the effects of SMMs. Our results not only illustrate the importance of examining the linear effects of SMMs, but also highlight the importance of examining interactions between SMMs and team processes in predicting outcomes. Thirdly, in addition to the substantive contribution of exploring potentially pervasive moderators, we examined those constructs over time, using repeated measurement design.

Practical Applications of the Findings

The findings from this study can be applied to team training. Team leaders should focus on team processes monitoring. Moreover, team members need to be aware and act in accordance with implicit rules that are likely to have an unexpected impact on team effectiveness even when there are some unclear details in the information or misunderstandings in the meeting prior to the mission. Once a team member is in a routine, the others will be on the right path, and the whole team will be enhanced. This effect is particularly relevant for teams working in urgent conditions with insufficient communication.

Limitations and Directions for Future Research

The present research was based on experimentally simulated project management team behaviors in the laboratory. Future researchers need to replicate these findings with more varied samples using a survey method and examining the interactions with other team types. Another avenue for future research would be to explore the generalizability of these findings with mature teams who have more coordination experience. The convergence between team leaders' and members' mental models may impact on team interactions. Researchers of studies exploring the correctness of mental models may be able to provide further evidence of the effects of SMMs.

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