THE COSTS OF SWITCHING BETWEEN TEAM AND MULTITEAM TASKS, AND THE ROLE OF SHARED COGNITION

A Thesis
Presented to
The Academic Faculty

by

Gabriel Plummer

In Partial Fulfillment
of the Requirements for the Degree
Master in the
College of Science

Georgia Institute of Technology
May 2017

THE COSTS OF SWITCHING BETWEEN TEAM AND MULTITEAM TASKS, AND THE ROLE OF SHARED COGNITION

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Date Approved: December 06, 2016

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Degree(s) Master of Science **Graduation date** May 2016

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ERRATA summary:

Original Appendix A is redacted per request of author and approval of advisor and graduate office.

Original Appendix B has been adapted and is now the revised Appendix A.

Errata pages have been inserted into the text to reflect this change.

ACKNOWLEDGEMENTS

I would like to thank my parents, Sarah Dinklage and Kevin Plummer, as well as my boyfriend, Wyatt DeLomba for supporting me and being there through stressful times. I would like to thank Raquel Asencio and Dorothy Carter for being fantastic mentors and helping me as I gained my footing in graduate school. Finally, I would like to thank my advisor, Leslie DeChurch who has been endlessly patient and helpful in this endeavor.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Many individuals work in teams. Many teams are interdependent with other teams. This requires that individuals engage in a specific form of multitasking to contribute to both their team and to other interdependent teams. This thesis extends research on task switching to examine the switch costs that accrue when individuals switch between tasks that vary in their interdependence. This study examined the degree to which having mental models that are more similar to ones teammates reduces the switch cost associated with moving between more and less interdependent work. This idea was tested in a laboratory experiment including 52 college students assigned to work in one of 19 teams. Each team was paired with another team to complete both “team” and “mutliteam” decision-making tasks. Mental models were measured using pairwise comparisons, and switch costs were calculated using the time it took to switch tasks. Findings reveal the more similar an individuals’ mental model to their teammates, the quicker the individual is able to switch between tasks with different levels of interdependence (team to multiteam or multiteam to team). No difference was found in the switch cost associated with transitioning up in interdependence (team to multiteam) or down in interdependence (multiteam to team). These findings have implications for how individuals are able to manage working in teams embedded in complex systems, and how team level cognitive processes facilitate task switching in those contexts.

Keywords: team, task management, task switching, shared cognition, team mental model, multiteam system

INTRODUCTION

Teams have been a major part of organizations for as long as organizations have existed. Over the past decades, organizations have been increasingly relying on the team structure due to the growing complexity of modern organizations and need for specialization (Sundstrom, 1999). Teams in organizations come in a variety of forms, and serve a variety of purposes such as product design teams, emergency response teams, task forces, special project teams, and many other variations. A team is defined as a distinguishable set of two or more people who interact dynamically, interdependently, and adaptively toward a common goal (Salas, Dickinson, Converse, & Tannenbaum, 1992)

Research on teams has primarily focused on internal processes and properties that enable effectiveness (Kozlowski & Ilgen, 2006) – cognition, cohesion, and coordination, to name a few. This research base supports the importance of team internal processes to team performance and viability (Ilgen & Hollenbeck, 2005). Additionally, two research streams focus on the external processes of teams, and their importance to team functioning: boundary spanning (Aldrich & Herker, 1972) and multiteam systems (Mathieu, Marks, & Zaccaro, 2001). Both lines of inquiry suggest that the manner in which teams interact with others outside the team plays an important role in their eventual success. The boundary spanning literature demonstrates the importance of bringing in information from the environment outside the team (Aldrich & Herker, 1977; O'Leary, Mortenson, & Woolley, 2011) as well as coordinating with other groups of people (Malone, 1987). The multiteam systems literature demonstrates the importance of coordinating the efforts of multiple specialized teams in order to accomplish complex overarching goals (Mathieu, Marks & Zaccaro, 2001).

The goal of this thesis is to explore the interface of internal team properties and external team processes. I focus on the internal team property, shared cognition, defined as members' shared, organized understanding and mental representations of knowledge or beliefs relevant to key elements of the team's task environment (Klimoski & Mohammed, 1994). I test the idea that shared cognition affects the speed at which individuals are able to manage their contributions to both team and multiteam work. Before developing these ideas further, I position this question within three literatures: mutliteam systems, task switching, and shared cognition.

Multiteam Systems

The increasing prevalence of teams creates a need in organizations where teams must interface effectively with other teams as multiteam systems (Mathieu, Marks, & Zaccaro, 2001). Consider the teams who respond to an emergency fire call. As soon as the call comes in, a local dispatch center has to communicate with the firefighters, police and EMT workers. Once at the scene, firefighting teams have to coordinate with the police, and EMTs, and the EMTs also have to coordinate with the staff team at the hospital who will be receiving the patients. These systems of interdependent teams are called multiteam systems (Mathieu, Marks, & Zaccaro, 2001). The definition of a multiteam system (MTS) is: two or more teams that interface directly and interdependently in response to environmental contingencies toward the accomplishment of collective goals. MTS boundaries are defined by virtue of the fact that all teams within the system, while pursuing different proximal goals, share at least one common distal goal; and in doing so exhibit input, process, and outcome interdependence with at least one other team in the system.

This thesis explores the issue of individuals who work on teams that are embedded in multiteam systems having to switch between tasks that require various levels of interdependence. For instance firefighters have their own individual tasks to perform, but also often need to work as a team on tasks, and there are also times they have coordinate with the other teams in the emergency response multiteam system. Switching between these groups is bound to come at some cost. This thesis seeks to answer: what are the costs of these switches in levels of interdependence, and what factors could ameliorate or exacerbate these costs?

An implication of teams' embeddedness in MTSs is that teams must switch back and forth performing tasks instrumental to proximal team goals, and then those instrumental to MTS tasks, and then back again. The firefighter at the scene of an accident needs to work with the firefighting team to put out the flames (team task), but also needs to cooperate with the police to set up the perimeter (MTS task), and get the victims out of the building and to a safe location (team task). Switching between tasks comes with certain costs such as delayed resumption of the goal that was switched from and poorer performance (such as more errors) when resuming a task or switching to another task (Altmann & Trafton, 2002; Engwall & Jerbrant, 2003; Hodgetts & Jones, 2006b; Monk, Trafton, & Boehm-Davis, 2008; Monsell, 2003; and Wylie & Allport, 2000). These performance costs of switching tasks often remain well after the switch occurs (Monsell, 2003). The existing literature on task switching focuses on individuals, offering little understanding to how these switches occur in the context of teams and larger social systems. This thesis expands the task switching literature by considering previously unexamined types of switches.

The literature on task switching, thus far, has focused on what McDonald, DeChurch, Asencio, Carter, Mesmer-Magnus, and Contractor term a *lateral switch*. A lateral switch is one that requires individuals to change one or more dimensions of work (e.g., task switches or tool switches; McDonald et al., 2015). In contrast, switching between tasks that require changes in the direction or degree of interdependence (e.g., switching upward from independent to interdependent work versus switching downward from interdependent to independent work) are what McDonald and colleagues term a *vertical switch*. Vertical switches are more complex than lateral switches because individuals have to adapt to a new task and to different sets of teammates who may have different norms or relations. When a team is focused on their team goal, they are attending to team level requirements, and developing team shared mental models of the task and interaction requirements. Given finite attention resources, the individual is not attending to interdependencies between teams. Therefore, when an individual switches to a multiteam task, they are less able to anticipate and execute actions. The task and interaction models that influence one's ability to switch between team and multiteam tasks are a part of between-team shared cognition.

Shared cognition is an emergent state that refers to the manner in which knowledge important to team functioning is mentally organized, represented, and distributed within the team (Kozlowski & Ilgen, 2006). Shared cognition provides members with the cognitive knowledge base to understand and anticipate other members' needs and actions without engaging in extensive communication. Shared cognition has consistently been shown to have an impact on performance at the team level (DeChurch & Mesmer-Magnus, 2010 and Kozlowski & Ilgen, 2006). However, the research on shared cognition has mostly dealt with single bounded teams even though, in reality, teams often operate in MTSs.

This thesis advances knowledge on how teams collaborate as a part of MTSs by exploring the costs of vertical switches (switching between team and multiteam tasks) to team and multiteam performance, and the role that shared cognition plays in facilitating or hindering these switches. Below, I review the literature on task switching and shared cognition as background for my hypotheses testing the effects of shared cognition on vertical task switches.

Task Switching

Research on MTSs has repeatedly described the challenges that ensue when teams are embedded in MTSs (DeChurch & Zaccaro, 2010). Empirical findings are quickly accumulating showing the difficulties that arise, as teams need to engage in coordination activities both internally as well as externally (O'Leary, Mortensen, & Woolley, 2011). MTS research has tended to approach this problem as a coordination issue, and focused solutions on understanding the motivational barriers to cross-team collaboration (Murase et al., 2014). This thesis takes a cognitive perspective, drawing on the individual task switching literature.

Task switching is when an individual shifts attention from one task to another (Monsell, 2003). Existing research on task switching has focused on individuals completing independent tasks; this thesis is concerned with the issue of team task switching. Team task switching encompasses switching between one or more dimensions of work (e.g. tasks, teammates, or tools) as well as switches in levels of interdependence such as when individuals switch from working alone, independently to working interdependently with their teammates on a team task (McDonald et al., 2015). Team task switching impacts the cognitive, motivational, behavioral, and performance effects that result when individuals respond to changing work demands within teams. The problem of task switching sits at the intersection of two main streams of research. The first is the literature on attractiveness and stickiness of tasks, which influences individuals' preferences to switch to alternate tasks versus sticking with their ongoing task (Payne, Duggan, & Neth, 2007; and Wickens, Santamaria, & Sebok, 2013). The second is the literature on switch costs that are incurred when people do an ongoing task, then are forced to switch to an alternative task, and then return to the ongoing task (Allport & Wylie, 1999; Monk, Trafton, & Boehm-Davis, 2008). While both types of switching do occur, this thesis is concerned with the switch costs associated with situations in which people are forced to switch tasks.

Switch costs. Even though individuals usually have some degree of control over what tasks they work on, there inevitably will be times when they are forced to switch to another task due to circumstances outside their control such as the urgency of the interrupting task, or supervisor demands. When people are interrupted or forced to switch between tasks, they incur switch costs. Switch costs have a direct bearing on performance adaptation*,* which refers to the "cognitive, affective, motivational, and behavioral modifications made in response to the demands of new or changing situational demands" (Baard, Rench, & Kozlowski, 2014). There are two main switch costs: 1) resumption lag, or the time required to resume a suspended task, and 2) performance which refers in general to amount of errors committed after switching to a new task or resuming a suspended task.

Characteristics of both the ongoing task and possible alternative tasks determine their effects on task switching performance and the amount of time required to return to the ongoing task following task switching (i.e., the "resumption lag"; Trafton, Altmann, Brock, & Mintz, 2003; Monk et al., 2008). For instance, Monk et al., found that the longer the interruption the greater the resumption lag. Trafton et al., demonstrated how rehearsal of the original task during the interrupting task facilitated the resumption process. Environmental cues have also been able to reduce resumption lag as long as they are prominent enough (Trafton, Altmann, & Brock, 2005). Additionally, researchers have found that the timing of interruptions affects the performance and overall time required to complete the ongoing task (Adamczyk & Bailey, 2004), and warnings or alerts of impending interruptions can ameliorate the resumption lag problem as well (Andrews, Ratwani, & Trafton, 2009; Brumby, Cox, Back, & Gould, 2013).

The current cognitive focus of the literature is mainly on individuals, and there is little done on team task switching, and no research about vertical switching between team and MTS levels. The cognitive factors that impact task switching at the team and MTS level will be different than those at the individual level. The reasons for resumption lag and errors at the team level and MTS level are different than those at the individual level. This thesis explores vertical task switching (changing the direction or degree of interdependence required to complete a unit of work) for the first time, and it looks at cognitive factors at the team level (specifically, shared mental models.

Shared Cognition

Prior research on shared cognition falls into two main categories: shared mental models (Cannon-Bowers, Salas, & Converse, 1993) and transactive memory systems (Wegner, Giuliano, & Hertel, 1985). One of the main differences between the two constructs is that shared mental models characterize common knowledge frameworks in a group, and transactive memory systems characterize distributed knowledge frameworks (Kozlowski & Ilgen, 2006). Whereas transactive memory research has traditionally emphasized task-oriented knowledge domains, shared mental models research has explored a wider array of cognitive content, including both taskwork and teamwork dimensions (Mathieu et al., 2000), in addition to exploring technology (Lim & Klein, 2006) and strategic mental models (Marks, Zaccaro, & Mathieu, 2000).

Another distinction is the dependent variables associated with transactive memory systems and shared mental models. Since encoding, storage, and retrieval of information are the main focuses of transactive memory systems, recall is usually the primary dependent variable measured in empirical work on transactive memory (e.g., Mell, van Knippenberg, & van Ginkel, 2013). In contrast, the emphasis in shared mental model research is on examining the impact of knowledge convergence on team processes (e.g., communication, coordination, performance monitoring) and performance (e.g., Mathieu et al., 2000). This thesis focuses solely on shared mental models in order to investigate how common knowledge structures impact an individual's ability to switch between team and multiteam tasks.

Shared mental models. In the 18th century, and persisting well into the 20th century, social psychologists were very interested in the concept of the group mind (i.e. Hegel, 1807, and McDougall, 1920). The group mind was a theory where experimenters analyzed groups much the same way they would individuals. Groups were believed to be sentient, and have mental processes that guided action. This theory, while similar to modern conceptions of shared cognition fell out of favor for being overly simplistic, and vague as well as being associated with extreme theories such as telepathy and other supernatural concepts. The group mind theorists also did not investigate communication processes among group members, and they identified the group mind with similar mental processes and contents of group members rather than having the group mind as a consequence or cause of group processes (Wegner, 1987).

Shared mental models emerged as a construct in 1990 by Cannon-Bowers and Salas to investigate performance differences in teams operating in complex, dynamic, and novel situations. Shared mental models are defined as the shared, organized understanding and mental representation of knowledge or beliefs relevant to key elements of the team's task environment (Klimoski & Mohammed, 1994). Cannon-Bowers and colleagues (1993) originally proposed four shared mental model domains: an equipment model (knowledge about tools and technology), a task model (understanding of work procedures, strategies, and contingency plans), a team interaction model (awareness of member responsibilities, role interdependencies, and communication patterns), and a team model (understanding of teammates' preferences, skills, and habits). In practice, however researchers have tended to collapse the content into two categories: 1) teamwork which entails knowing how to interact with team members, and knowing how one person's contribution fits in with other people's contributions and 2) taskwork which means knowing how to complete tasks and what the goals of the team are (Cooke, Kiekel, & Helm, 2001; Mathieu et al., 2000).

Shared mental models are measured on the properties of similarity and accuracy (Mohammad, Ferzandi, and Hamilton, 2010). Similarity is the degree to which meanings and understandings used to interpret internal and external events are alike among individuals. Rouse & Morris, (1986) assert that when team members share knowledge, it enables them to interpret cues in a similar manner, make compatible decisions, and take the appropriate action. However, when mental models overlap too much it becomes a detriment to the team because it limits unique individual contribution (Cannon-Bowers et al., 1993 and Levine et al., 1993). Cannon-Bowers et al. clarify that shared mental models do not imply identical mental models; rather, team members hold compatible models that lead to common expectations. Accuracy refers to the extent that shared mental models reflect the true nature of the world (Edwards et al., 2006). It is important for both to be measured because teams that have false but similar mental models are likely to perform worse than teams that are both similar and accurate (Mohammad et al., 2010). New groups typically go through a "forming" stage where team members share ideas about how they will work together, and their expectations about the tasks. Team members, usually reach, at least a minimal amount of understanding about the nature of the team, its tasks, and goals, and how the team will interact together (Klimoski & Mohammad, 1994).

From its conception in 1990, it took approximately 10 years before articles were published that directly measured shared mental models and its antecedents and outcomes. Seeing as Cannon-Bowers and Salas (1990) first conceived of the idea to explain performance differences in teams, it makes sense that team performance has been the dominant outcome measured in association with shared mental models. The general thesis was that team effectiveness would be improved when the team shared an understanding of the task, team, equipment, and situation (the four categories Cannon-Bowers et al., 1993 proposed). Shared mental model similarity has in fact been shown to have a significant impact on team effectiveness and team performance across a wide variety of teams, and situations (For reviews, see DeChurch & Mesmer-Magnus, 2010, and Kozlowski & Ilgen, 2006). For instance, Minionis, Zaccaro, and Perez (1995) used a computer based tank simulation, and showed that shared mental models improved performance on collective tasks requiring interdependence among team members. In this study, shared mental models did not predict better performance on tasks that did not require coordinated action which is in line with the original predictions of the theory. For a more realistic examination of shared mental models, Lim and Klein (2006) conducted a field study on combat teams in the Singapore armed forces and found that task work and teamwork mental model similarity and accuracy both predicted team performance.

In addition to team performance, shared mental model similarity has also been positively associated with team processes like communication, coordination, backup behaviors, collective team efficacy, strategy implementation, engagement, and less attention to time. Studies have shown that these team processes mediate the relationship between shared mental model similarity and performance (Gurtner et al., 2007; Marks et al., 2002; Mathieu et al., 2005; Mathieu et al., 2000). Mathieu et al., in 2005, used a computer based combat flight simulation and showed that teamwork and task work mental models predicted team processes and team performance, and showed that the team processes partially mediated the relationship between the shared mental models and performance. Mesmer-Magnus and DeChurch (2009) conducted a meta-analysis that showed a positive relationship between information sharing and team performance. Conversely, Bearman et al., (2010) found that breakdowns in communication led to less effective functioning. This would imply that, when shared mental models are prevented from forming, there is a breakdown in team processes that leads to worse performance.

After the theoretical development on shared mental models, the researchers spent the majority of time establishing a relationship between them and team performance. However, eventually, people began to investigate factors that fostered shared mental model development. One of the earlier studies to investigate shared mental model antecedents was the one done by

Stout et al., (1999). They measured the planning behaviors of teams performing a low-fidelity tank helicopter flight simulation. Planning included factors such as goal setting, discussing expectations and roles, clarifying timing of events, and planning for unexpected or high workload conditions. They found that teams that planned a lot had better shared mental models than teams that didn't plan much. Improved mental models led to better communication and coordination that led to better team performance.

Some people studied inputs such as team member characteristics such as gender, age, experience, and ability (Edwards et al., 2006 and Rentsch & Klimoski, 2001). Edwards et al. had dyads of uniformly high, or low ability, or mixed ability complete an aviation simulation task. They found that general mental ability predicted similarity and accuracy of shared mental models that, in turn, predicted performance on the task. Rentsch and Klimoski surveyed teams of various sizes and compositions from a US Department of Defense organization. They found that certain attributes of team composition were positively related to shared mental models such as percentage of members with high experience, education similarity, and level similarity. However other composition attributes like age and gender homogeneity did not predict shared mental model formation. Additionally, team size was negatively associated with shared mental models so the bigger the group; the harder it was to share information and form a shared mental model. Finally, this study, like Edwards et al. showed that these antecedents associated with shared mental models predicted team performance, and that the mental models mediated that relationship.

Other researchers have investigated how various interventions such as training programs pre-planning sessions, or other interventions could influence the development of shared mental models (Cooke et al., 2003; Gurtner et al., 2007; Marks et al., 2002; Marks, Zaccaro, & Mathieu, 2000; Smith-Jentsch et al., 2008; and Stout et al., 1999). The most common training method found to increase teamwork and task work mental models is cross training (i.e. Cooke et al., 2003 and Marks et al., 2002). Cross training is an instructional strategy in which each team member is trained in the duties of his or her teammates (Volpe, Cannon-Bowers, Salas, & Spector, 1996). Marks et al. used three person helicopter flying simulation teams, and manipulated whether members received some level of cross training or some control irrelevant training. They found that cross training improved the development of teamwork mental models which led to increased coordination, communication, and backup behaviors, naturally leading to better performance than groups in the control condition. Cooke et al. also found that teams exposed to cross training acquired more taskwork and teamwork knowledge than control teams or teams exposed to a conceptual version of cross training. Another form of training intervention that Marks, Zaccaro, and Mathieu found to be influential to shared mental model development was team interaction training which involves training of task information embedded in the necessary teamwork skills for effective team task execution. The content of this training refers to how to work better as a team, not how to perform the task requirements better per se. Other interventions that improve shared mental models include leadership pre-briefings (Marks, Zaccaro, & Mathieu, 2000), and reflexivity training (Gurtner et al., 2007) which is training to reflect upon the group's objectives, strategies, and processes and adapt them to current or anticipated endogenous or environmental circumstances.

Hypotheses

Socio-cognitive switch costs. One of the principal differences between switching tasks laterally (at the same level of interdependence) and switching tasks vertically (changing level of interdependence) is the nature of the cognitive demands. When an individual switches tasks laterally, they experience a switch cost, defined as the difference in performance and accuracy between repeating a task, and switching from one task to a different one. In a team, switching from working with one's teammates to coordinating across teams carries a similar switch cost, but instead of conceptualizing the cost in terms of time lost because of cognitive processing demands, we can understand it as time lost as the individual must switch from one set of team cognitive architecture (i.e., mental model similarity) to another. People have to quickly remember or figure out their duties and who they need to interact with for this new task.

Since we are considering switching between levels of interdependence, it is useful to understand both mutliteam switch cost and team switch cost. Multiteam switch cost is defined as the performance and accuracy decreases associated with switching from working with an individual team to having to coordinate across teams in a multiteam system (see Figure 1). In comparison, a team switch cost is the performance and accuracy decreases associated with switching from coordinating across multiple teams to working with an individual team. In both cases, the switch cost is characterized as the time it takes to resume the task.

Shared cognition, while integral to smooth interactions within the team, creates inertia making switches from the team to system more challenging. As cognition is shared within the team, it makes it more difficult to switch to MTS work because people on the team get entrained to a particular working style (McGrath & Kelly, 1986). When an individual spends a great deal of time working in one task mode (e.g., on independent task functions or with a particular team), he or she may be highly entrained to a work mode (speed, efficiency, quality) that does not translate efficiently and effectively to the multiteam context, resulting in breakdowns in performance. Teams learn to follow paths of functions at different modes of team activity at different times (McGrath, 1991). Over time, teams synchronize their interaction patterns, task production rates, and communication timing (McGrath, Arrow, & Berdahl, 2000). Therefore, getting highly entrained at one level of task work will be more disruptive (than being less entrained) when forced to switch to another level of task work. This disruption leads to increased multiteam switch cost, which is the time it takes to resume a multiteam task after previously working on a team task.

Developing mental models similar within a team may improve coordination within that team, but it also will make it difficult when the team suddenly has to adapt to new networks of information and communication. The same goes for transactive memory systems. A person can become too entrained to one system of information that when they switch to a multiteam task, their system of who knows what is incorrect. It becomes harder to break away from what you know, leading to more errors, and asking the wrong people for information. Therefore:

Hypothesis 1: Shared mental model similarity is positively related to multiteam switch costs.

Within the team, however, shared cognition allows members to predict one another's actions, to anticipate one another's behavior. In short, it allows members to make accurate assumptions about one another's future behavior (Mathieu et al., 2000). It is essential for team functioning like when a firefighter team responds to an emergency, when they have similar shared mental models, they don't have to waste much time figuring out who is going to do what, and can act quickly, anticipating what the other members of their team will do. When a team is good at anticipating each other's actions and coordinating seamlessly, then the team will not be as disrupted by shifting their cognitive focus. Therefore, shared cognition will lead to a decrease in team switch costs, which is the time it takes to resume a team task after previously working on a multiteam task. When working on a team, you also become acquainted with who knows what and who you need to go to for specific information. This cuts down on the amount of time spent trying to figure out where information is located in the team, and reduces the cognitive burden of everyone trying to learn and know everything (Kyle, 2004). Therefore:

Hypothesis 2: Shared mental model similarity is negatively related to team switch costs.

Upward switching versus downward switching. An important reality of teams working in systems is that switches are required in both directions. Teams need to shift to work as systems, but they also need to break away from boundary spanning and resume working internally (O'Leary, Mortensen, & Woolley, 2011). Paramedics at the scene of an accident have to work with their teammates to administer first aid to the victims, and they also have to sometimes switch to working with the team back at the hospital to coordinate the number of people they are bringing in, and what they need to be prepared to receive. An upward switch reflects an increase in the complexity of teamwork, there is greater interdependence, and individuals must manage both internal and external interdependencies simultaneously. A downward switch is also challenging, but in a different way. With a downward switch, the individual goes from working at a higher level of interdependence to a lower level (e.g., working with the multiteam system to working just with teammates). This means:

Hypothesis 3: Upward switching (i.e., from team to MTS) will incur greater switch costs than downward switching (i.e., from MTS to team).

Method

Participants

Research participants included 60 college students recruited through the Psychology subject pool at a midsize southeastern university, who were arranged into 20 three-person teams working in one of 10 two-team multiteam systems. Participation in this study was voluntary, and participants were informed that they could withdraw from the study at any time. Participants who completed the study were given the choice to receive course participation credit for their time or cash compensation of $30. Due to missing switch time data, 8 individuals had to be excluded from final analyses, and so the final analyses sample consisted of 52 individuals (30 men and 22 women). The literature indicates that shared mental model similarity has a moderate effect on outcomes such as team performance and team processes (DeChurch & Mesmer-Magnus, 2010) so an a priori power analysis was performed using a program called G*Power to detect a medium effect size of $f = .25$, with an alpha of .05 and a desired power of .8. The output indicated I would need a sample of 46 individuals to detect the desired effect.

Research Design

The study took place in a laboratory setting using a 90-minute series of survival simulation tasks including training on how to complete the tasks. Individuals received a shared cognition manipulation at the beginning of the session. This study was conducted in a laboratory setting in order to carefully observe task switching and manipulate the degree of similarity of individual's mental models to their teammates.

The study utilized a mixed, within- and between-subjects design. Each individual was observed making a total of 14 task transitions: 5 upward and 5 downward in terms of interdependence, and 4 lateral switches where the task changed but not the degree of interdependence. The degree to which individuals' mental models were similar to their teammates was manipulated between-subjects, with 33 individuals receiving training intended to produce similar mental models, and 19 individuals receiving training intended to produce dissimilar mental models.

Manipulation

Teammate mental model similarity. Team mental models characterize the arrangement of knowledge about the team or task. The degree to which individuals held mental models similar or dissimilar from their teammates was manipulated with training. Individuals in the similar condition received the same instructions as their teammates on what strategy to use to complete their task. Individuals in the dissimilar condition each received a different strategy from their teammates.

The training was delivered with a 5-minute task training video immediately following a 5-minute general instruction video. The goal of this training was to manipulate how people viewed the interrelatedness of elements of their task. There were a total of 3 strategies for completing the task: functional similarity, item individuality, and hi/low priority. In the functional similarity strategy, participants were instructed that the best way to conceptualize the task in order to be successful was to view the items on the list and categorize them based on functional purpose. In the item individuality strategy, participants were instructed that evaluating the uniqueness of each item and how it uniquely could be used unrelated to other items would be the most successful strategy. In the hi/low priority strategy, participants were instructed that the best way to complete the task was to focus on how items were related based on how crucial (or not crucial) they were for survival. Each testing session was randomly assigned to the similar or dissimilar condition. In each session, individuals were assigned one of six roles by randomly choosing a nametag when they arrived, and three of the roles corresponded to one set of team members and the other three corresponded to the second team.

In order to determine the degree to which the manipulation produced the intended differences in individuals' mental model similarity to teammates, the teams completed a practice task and responded to a mental model measure. The practice task was identical to the decision tasks used in the main data collection. After completing the practice task, individuals completed a survey asking about the strategy that he or she employed during the training. The survey presented a list of the three possible strategies and asked which of the following strategies did you use to complete the survival task. Response options included functional similarity, item individuality, and hi/low priority to correspond to the terms participants might have seen in the training. This measure was then used to determine: (1) whether or not individuals were using the strategies they were assigned, and (2) the degree to which members of the same team were electing to use the same strategy, i.e., the degree to which the manipulation produced the intended level of similarity. If the manipulation had the intended effect, then individuals in the similar condition should be selecting the same strategies as their teammates, whereas individuals in the dissimilar individual mental model similarity with teammates condition should all be selecting different strategies than their teammates. Everyone should be selecting the strategy that they were trained to use.

Manipulation Check Results

In order to assess the degree to which the training resulted in the intended differences in participants' mental models, participants completed a survey following the session. This measure asked participants to rate the relatedness of all pairs of items from their team task. Scores for individual mental model similarity with teammates were obtained by averaging the C index scores (Marks et al., 2002) for the overlap between an individual and the two teammates. C index scores are computed by feeding individuals' relatedness ratings into Pathfinder (Schvaneveldt, 1990), which assesses the amount of overlap between each pair of member relatedness ratings matrices where 0 indicates no overlap and 1 indicates complete overlap. A Welch's t-test was used to determine the difference in individual mental model similarity with teammates for people in the similar condition compared to people in the dissimilar condition. Descriptive statistics for the two conditions can be found in Table 1. Welch's t-test is preferred to a standard t-test in this situation because the sample sizes of the two conditions (similar and dissimilar) were different (n = 33 versus n = 19), and Welch's is more appropriate when the two samples have unequal variances and unequal sample sizes (Welch, 1947). Examining Table 1, shows individuals' mental model similarity with teammates was higher in the dissimilar condition (Similarity = 0.446) compared to the similar condition (Similarity = 0.294). This was in the opposite direction meaning the manipulation intended to produce more similar mental models actually led to more dissimilar mental models. A t-test shows this difference is statistically significant, $t(30) = -3.80$, $p < .01$.

Table 1

Mental Model Similarity Scores for Individuals Assigned to the Similar and Dissimilar Conditions

	N (individuals)	Mean	SD	Min	Max
Similar	33	0.294	0.113	0.122	0.520
Dissimilar	19	0.446	0.152	0.225	0.769

To further investigate the effect of the training manipulation on individual mental model similarity with teammates, a second manipulation check asked participants to report the strategy they used to complete the task. This was a categorical question where participants were presented a list of possible options, and participants chose the strategy they used. The data were organized into observed value cells based off the strategy they were assigned and the strategy they reported using. Descriptive statistics showing the breakdown of participants' assigned strategy combined with chosen strategy can be seen in Table 2. A chi square test of independence was run to test if chosen strategies differed across assigned strategy categories. Results were not significant, X^2 (4, N = 52) = 6.24, $p > .05$ indicating that chosen strategy did not differ by assigned strategy. Table 2 also shows that if all participants indicated that they used the strategy that they were assigned to, there would be 23 members using the functional similarity strategy, 23 members using the item individuality strategy, and 6 participants using the hi/low priority strategy. The descriptive statistics show that only 6 participants chose the functional similarity strategy out of the 23 assigned to that strategy condition. Similarly, only 9 participants used the item individuality strategy out of the 23 assigned, and 4 participants used the hi/low priority strategy out of the 6 assigned. These descriptive statistics indicate that fewer than half of the participants actually chose to use the strategy they were assigned to.

Table 2

Number of Participants Broken Down by Assigned Strategy and Chosen Decision Strategy

		Chosen Strategy			
		Functional Similarity	Item Individuality	Hi/low Priority	Total
Assigned Strategy	Functional Similarity	$n = 6$	$n = 9$	$n = 8$	23
	Item Individuality	$n = 4$	$n = 9$	$n = 10$	23
	Hi/low Priority	$n = 1$	$n = 1$	$n = 4$	6
	Total	11	19	22	52

Taken together, both manipulation checks suggest the manipulation did not affect participant's mental models as expected. And so, mental model similarity was treated as a measured predictor variable, and not a manipulated independent variable in the analyses.

Team and Multiteam Tasks

This study used a multiteam system survival simulation scenario where two teams had to alternate between teamwork and multiteam work to complete various survival tasks where they were asked to rank order a list of items from most important to least important in terms of their use for completing their mission. In total, each team had three tasks: (1) a multiteam task, (2) a team task, and (3) an alternate team task. Teams were instructed that they were members of a National Guard rescue squad made up of two teams (a land team and an ocean team). Their tasks were to plan for 3 different survival training scenarios. The general format of these tasks is that the team is given a scenario where they are to be stranded e.g. "You are going to be dropped off in the Northern area of Siberia. Your team has to stick together, and the items are in good condition unless otherwise stated. The goal is to pack items that will best help you to survive, and aid in being rescued." The team then is given a list of equipment that includes items such as clothing, compass, maps, mirrors, weapons, etc. The expectation is that not everything can go with the team on the training mission so they had to prioritize items that were most important or else risk not having them on the mission.

Multiteam task. The multiteam task involved both teams working together to make a combined ranking of two 15-item lists. They are told that one team is going to the desert, and one team is going to be dropped in the ocean off the coast of that desert. Due to the proximity of the missions, the teams were told they would need to share a transport and plan which items to prioritize from both lists. Each team's goal was to prioritize items from their team's list to ensure the success of their team, but they also had a multiteam system goal of ensuring the health of as many people as possible from both teams. The teams were located in separate rooms so communication between teams occurred through a chat interface. However, team members were collocated so within team communication was in person.

Team task. The team tasks were the same as each team's portion of the multiteam task except they were told that a second transport had become available so they needed to create an ideal ranking of just their team's items. The scenarios were the same as the multiteam task – the land team was set to be dropped in the desert, and the ocean team was set to be dropped off the coast of that desert, but now teams could prioritize just items from their list without worrying about what items the other team had to bring. During this task, there was only within team communication and no dialogue between teams.

Alternate team task. The alternate team task was the same for both teams, although each team worked on it separately. This scenario involved being dropped off in the arctic so the item list was significantly different from both the desert survival and ocean survival. For this task, the teams would not be together so there was only within team communication just like the team task.

Tools

Google docs. Teams completed these three tasks in Google docs on Google drive. Google docs are online collaborative word documents where whoever has access to the document can make edits. Using Google docs allowed team members to collaborate to fill out a single sheet for each of the team tasks where members could each make edits on their own computers and also see the edits other people were making on the same task. There was also a single sheet to fill out for the multiteam task for both teams to collaborate at the same time. For the tasks, teams were collocated in the same room, but each team was in a different room. Therefore, teams could talk to each other out loud, but between team communications had to go through online chatting using Google chat. The Google chat was only available to people while they worked on the multiteam task. There was no between team communication allowed while teams were working on their respective team or alternate team tasks. Each task (multiteam, team and alternate team) was located on a separate document, and experimenters opened these documents on 3 different tabs. Only members on the same team had access to their team and alternate team task, but both teams had access to the multiteam task. Each document had the survival scenario at the top, followed by a list of items, and then a brief paragraph explaining the guidelines of the task. Then there was a ranking sheet with the items filled in in one column, and an empty column to the right for the team to fill in the ranking for each item.

Morae. In order to track how long it took for an individual to switch from one of the tabs to another, a usability software called Morae (SoftTronics, Lutz, & Kretzschmar, 2003) was used. Morae (Moore & Dickson-Dean, 2010) runs in the background of the participant's computer and records the actions taken on the computer. It also conveniently marks various activities such as tab switches with time stamps. Morae also allows an administrator to send pop ups that appear on participants' computers. These were used to instruct participants when they needed to switch to a certain task. Morae also records time stamps of when these pop-ups were sent, and when they were acknowledged.

Procedure

Participants were randomly assigned to teams (Land Team or Ocean Team) and usernames (Alpha, Bravo, Charlie, Delta, Echo, or Foxtrot). Teams were seated in separate rooms, and each watched their first general instruction training video. This video was 5 minutes long and provided background information about the teams and the task, and then gave instructions on how to complete the tasks as well as how they would be instructed to switch between the tasks with the pop-ups. After the first training video, teams were instructed to watch a second video individually using headphones. This 5-minute video was their strategy training video meant to manipulate the similarity of individuals' mental models with their teammates. There were three possible strategy training videos: 1) Functional similarity where individuals were told to view the items on the list and categorize them based on functional purpose, 2) Item individuality where individuals were told to evaluate the uniqueness of each item and how it uniquely could be used unrelated to other items, and 3) Hi/low priority where individuals were told to focus on how items related based on how crucial (or not crucial) they were for survival. If individuals on a team were in the similar individual mental model with teammates condition then everyone on the team received the same strategy training video. If they were in the dissimilar individual mental model with teammates condition then each member on the team saw a different video. In total, there were 33 individuals in the similar condition and 19 individual in the dissimilar condition.

Following the videos teams were given a chance to practice completing survival tasks using the strategies they learned, and get used to switching between multiple tasks. The teams did not work together during the practice, but each team had two practice tasks that they would get to work on for 5 minutes. Experimenters pulled up a browser window with two Google docs in two separate tabs (one tab for each task). The instructions were clear that nobody is to work on a task unless instructed to switch to it by a pop-up. There is no switching between tabs allowed otherwise, but when instructed to switch by a pop-up, those instructions must be followed and remaining to work on the same task is not an option. Once both teams were ready, they were told to begin. Two minutes into the task, they received a pop-up telling them to switch to the second tab. Two minutes later, a pop-up told them to switch back, and one minute later, the practice was concluded. With just 5 minutes, teams were not expected to complete the practice tasks, but rather this was to give them practice using their assigned strategy and also get used to switching to another task when they saw the pop-ups.

After the training concluded, participants are instructed to take a survey testing the manipulation from the training. They were given a list of the possible strategies, and asked which one they personally used based on their training. After the brief survey, they were told to continue using the same strategy for the rest of the tasks.

Once everyone was done with the manipulation check survey, the session began. Experimenters pulled up the window with the three Google docs open on three different tabs.

Everyone began on their team task, and reminded not to switch to another tab unless directed to do so by the pop-ups. They were told that in total, they would have five intervals to work on each task and a total of just less than 23 minutes to finish all three. When participants needed to be instructed to switch to their multiteam task, a pop-up was sent through Morae that simply said MASTER (for master list). Participants were trained on what this meant so they closed out the pop-up and immediately switched to the multiteam task tab. To switch participants to the team task, they saw a pop-up that said TEAM, and to switch to the alternate team task, they received a pop-up that said SIBERIA (because the task took place in Siberia). The time intervals were randomly generated to be between 60-120 seconds, and kept the same for each session. The switching schedule is seen in Table 3, and shows the time the switch pop-up was sent, and which task that pop-up directed participants to switch. People started on their team task and made 14 switches to other tasks. Five of those switches were from one of their team tasks (team task or alternate team task) to the multiteam task, five of the switches were from the multiteam task to one of their team tasks, and four of the switches were from either team task to alternate team task or vice versa. Using this schedule, there were five upward switches (team-multiteam), five downward switches (multiteam-team), and four lateral switches (team-team).

Following the final time interval, participants were notified of the task's conclusion, and given a survey to assess team characteristics and states, most important being each individual's mental model. The Morae recordings of the session were saved and stored for analysis.

Table 3

Task Switching Schedule

Time	Switch #	Task to switch to
0:00	START	TEAM
1:35	Switch 1	MASTER
3:12	Switch 2	SIBERIA
4:42	Switch 3	TEAM
6:09	Switch 4	SIBERIA
7:51	Switch 5	MASTER
9:17	Switch 6	TEAM
10:59	Switch 7	MASTER
12:15	Switch 8	SIBERIA
13:52	Switch 9	TEAM
15:25	Switch 10	SIBERIA
16:55	Switch 11	MASTER
18:18	Switch 12	TEAM
19:42	Switch 13	MASTER
21:03	Switch 14	SIBERIA
22:30	END	

Measures

Team switch costs. Team switch costs were operationalized as the time it takes for an individual to switch from a multiteam task to a team task (see Figure 1a). These multiteam to team switch times were recorded and measured using Moray software (SoftTronics, Lutz, & Kretzschmar, 2003). As described in the above procedure, participants were forced to switch tasks using pop-up messages. Therefore the team switch cost was the time it took from when an individual working on a multiteam task acknowledged the pop-up telling him or her to switch to one of the team tasks to when that individual clicked on that team task tab. All of these events were recorded and time stamped in the Morae recordings. The downward switches included ones from the multiteam task (MASTER) to the team task (TEAM) as well as switches from the multiteam task to the alternate team task (SIBERIA).

Multiteam switch costs. A multiteam switch was operationalized as when an individual switches from a team task to a multiteam task (see Figure 1b). Just like the team switch costs, multiteam switch costs were the time it took for an individual working on a team task acknowledging a pop-up instructing him or her to switch to the multiteam task to the time that the individual clicked to open the multiteam task tab. These upward switches included switches from TEAM to MASTER as well as from SIBERIA to master.

Lateral switch costs. Although my hypotheses only concern team and multiteam switch costs, individuals did make lateral switches so lateral switch costs were measured as well. A lateral switch was when an individual switched from working on one team task whether it be TEAM or SIBERIA to working on the other team task (see Figure 1c). Lateral switch costs were measured in the same way as the other switch costs with the time between the firing of the pop-ups and the switching to the different tab.

Mental models. Since the manipulation of mental models was mainly concerned with task elements, only task mental models were measured. Participants completed pairwise comparisons, a technique, commonly used to assess mental models (Mohammed, Ferzandi, & Hamilton, 2010). Participants were given the items from their team list and asked to rate how related each pair of items were on a scale of 1 (totally unrelated) to 7 (very strongly related). The mental model measure can be seen in the form it was presented in Appendix A. The reasoning is that individuals with mental models similar to his or her teammates saw the item lists through a similar lens and grouped those items more similarly compared to individuals who had dissimilar mental models with their teammates.

Individual mental model similarity with teammates was assessed using pathfinder (Schvaneveldt, 1990) going along with the procedure suggested by Kraiger and Wenzel (1997), and one that has been used frequently in past mental model research (e.g. Marks et al., 2002; Lim & Klein, 2006; and Stout et al., 1999). Pathfinder is a software that creates a network of individuals' paired comparisons and then can assess the overlap of two individuals' networks giving each pair of networks a C rating based on how much overlap there is with 0 indicating no overlap and 1 indicating total overlap. An individual's mental model similarity with teammates was calculated by averaging the C rating to each of the two teammates. In this way, each individual got an average mental model similarity rating based on how similar he or she was to his or her two teammates. The reason that an individual's similarity rating is the better indicator of how entrained the individual is in the team compared to the team's overall mental model similarity is because the switch times are measured at the individual level.

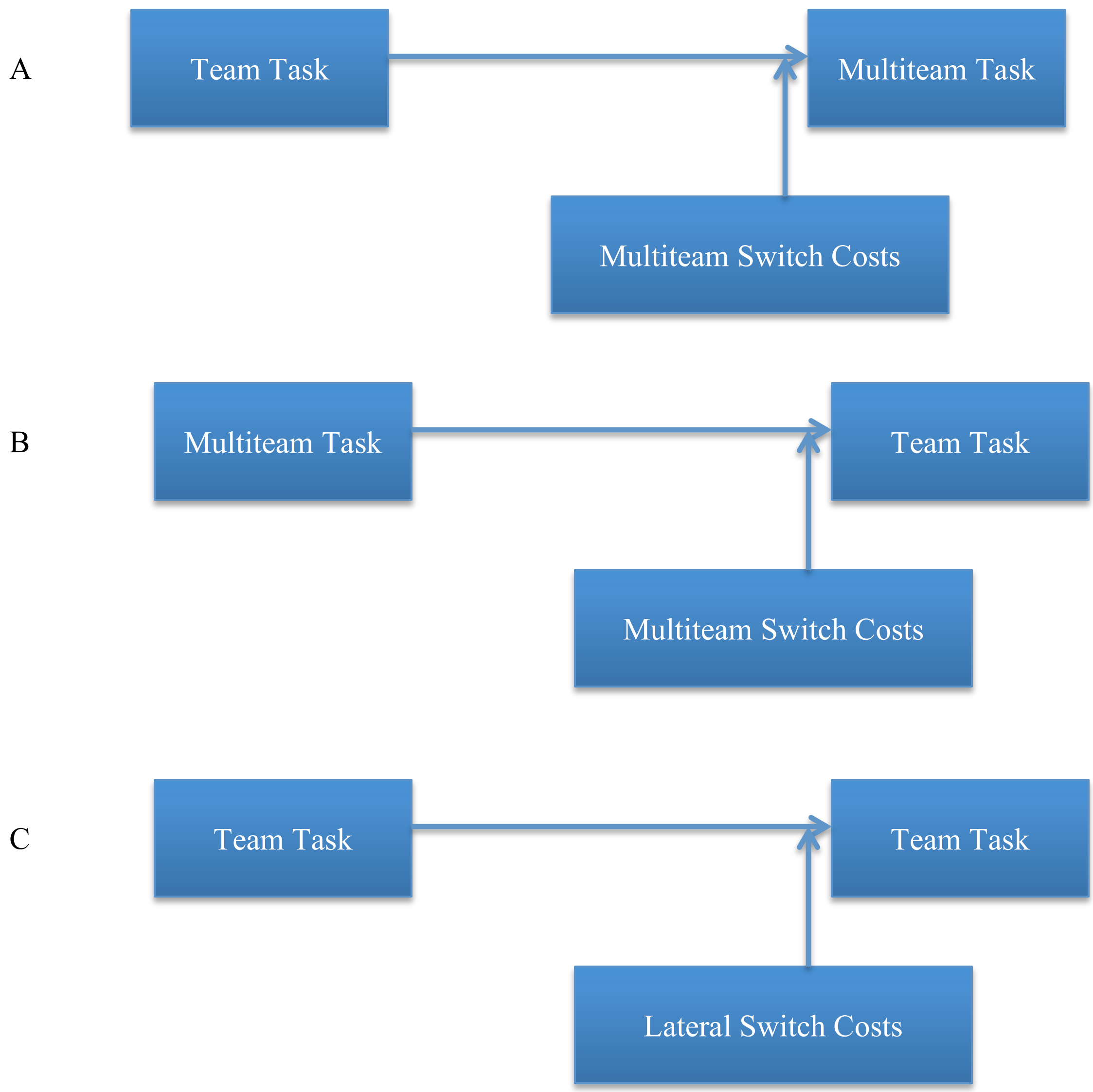

Figure 1. Three types of switch costs: **A** depicts a team switch cost, **B** illustrates a multiteam switch cost, and **C** illustrates a lateral switch cost.

Results

The level of analysis for all analyses is the switch, though because individuals performed multiple switches, and individuals worked in teams, I used multilevel analysis to control for non-independence due to individual performing the switch and team membership. Task switching was analyzed in a 3-level multi-level model with individuals nested in time periods and teams. Level 1 is time; there were five periods in which switch time measurements were taken for both upward and downward switches, and there were four periods in which lateral switch time were measured. Level 2 is the individual; there were 52 individuals each of whom made five upward switches, five downward switches, and four lateral switches. Level 3 is the team, each individual was a member of one of 19 teams.

In this section I first present the results of the manipulation checks to verify that the training resulted in expected variations in participants' mental models. Second, I present ICCs examining the degree to which the individual and team was a meaningful source of variance. Third, I present analyses testing each of the focal hypotheses. Fourth, I present supplemental analyses examining lateral task switching.

Multilevel Data

Because switch times were measured multiple times for each individual, the intraclass correlation coefficients (ICC1) were calculated to assess the proportion of variance in switch times due to the individual. A substantial amount of variation at the individual and/or team level would support the need to control for these grouping factors in a multilevel analysis (Bliese, 2000). In the literature, ICC1s over .3 are rarely seen, and values are typically between .05 and .20 so a general rule of thumb is that ICC1s above .10 justifies aggregation, or implies a need to control for group variance in a multilevel analysis (Klein & Kozlowski, 2000). The observed ICCs indicate significant variability due to the individual for each switch type: upward switches (ICC1 = .26), downward switches (ICC1 = .10), and lateral switches (ICC1 = .31). However, the ICC1s suggested less variance was attributable to the team as the grouping factor. The ICC1 for upward switches was .05, for lateral switches .07, and for downward switches .11. Taken together, the relatively high ICC1's at the person level, and relatively low ICC1's at the team level suggest analyses be conducted using hierarchical linear modeling with the dependent variables, switches, modeled as observed switches nested within individuals over time. Because of the .11 ICC due to "team" on downward switches, analyses were also run using a 3-level multilevel model.

Hypothesis Testing

Given the results of the ICC1s, the hypotheses were first tested using hierarchical linear modeling with a two-level nested structure: time points (switch time measurement occasions) nested within individuals. To run the analyses, the lme4 package in r (Bates et al., 2015) was used. The data for switch time can be seen in Figures 2-4 for each type of switch (upward, downward, and lateral). An outlier analysis was performed on the switch times by calculating 1.5 times the interquartile range (IQR) and considering outliers as those observations falling above the 3rd quartile or below the 1st quartile. This procedure identified 61 outliers; 58 observations of switches were longer than the 3rd quartile and 3 were faster than the first quartile. I eliminated these values as faster switches likely reflect the fact that the individual anticipated the switch or switched early before being told and extremely slow switches likely indicate that there was a glitch in the technology where the individual did not receive the pop-up in time or the pop-up did not go away when dismissed. The trimmed data is shown in Figures 5-7.

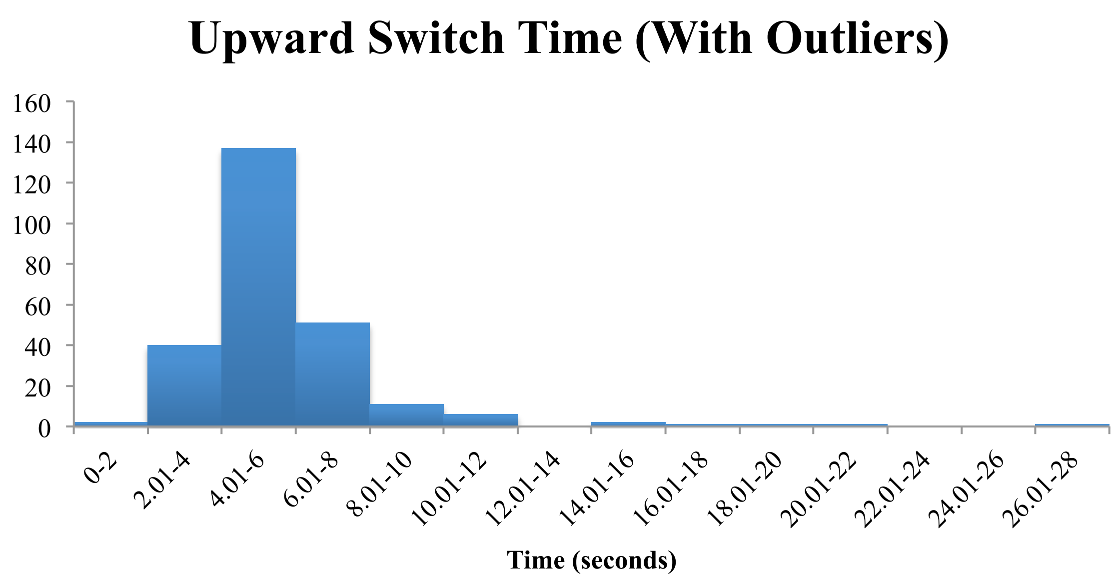

Figure 2. Upward switch times (outliers included)

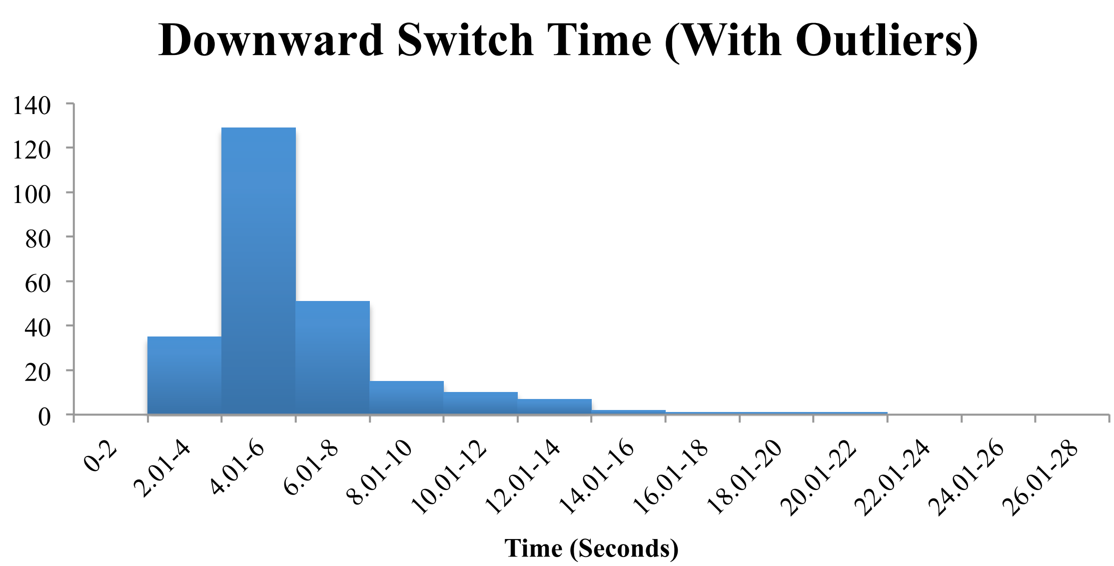

Figure 3. Downward switch times (outliers included)

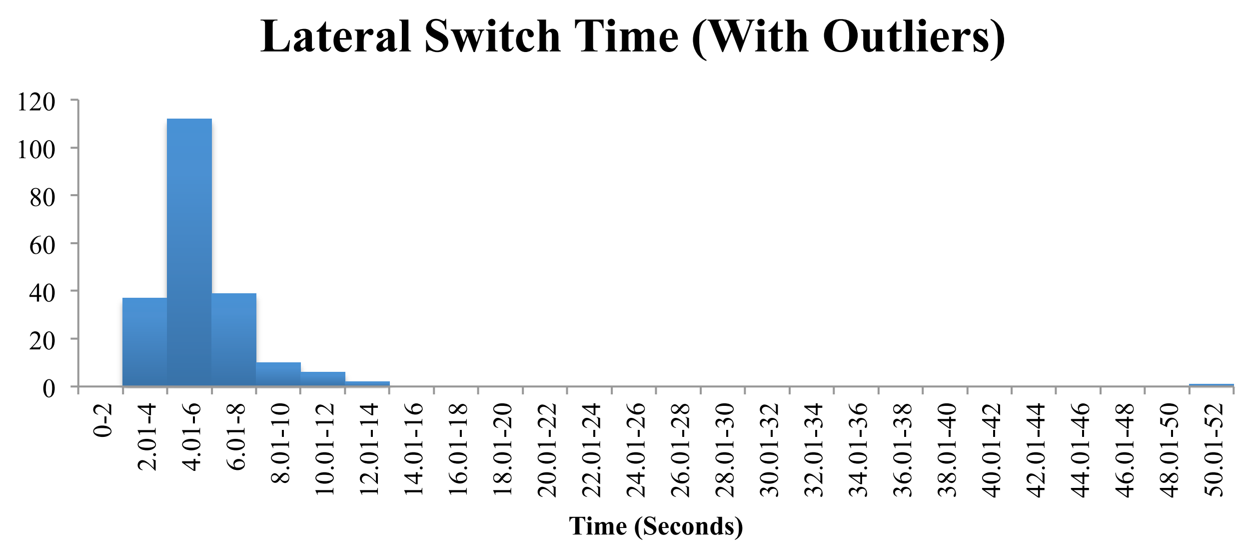

Figure 4. Lateral switch times (outliers included)

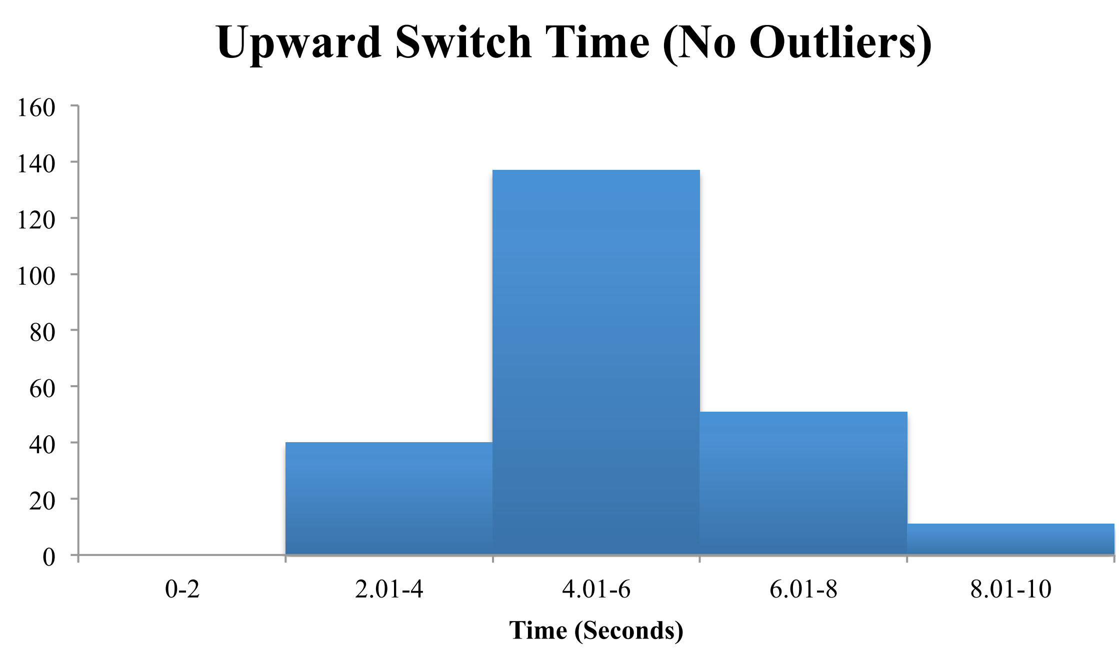

Figure 5. Upward switch times (outliers excluded)

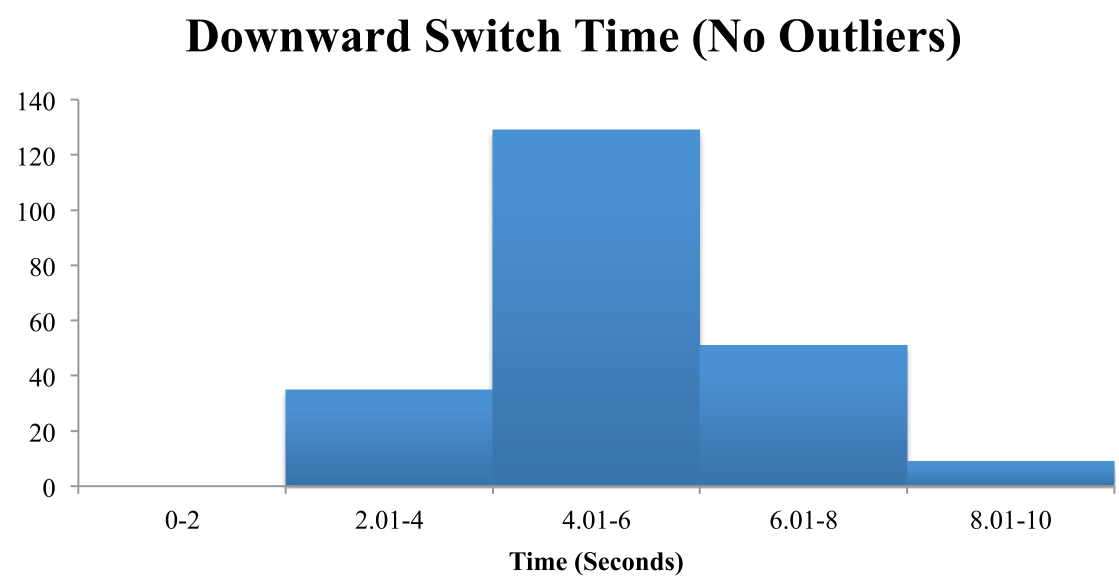

Figure 6. *Downward switch times (outliers excluded)*

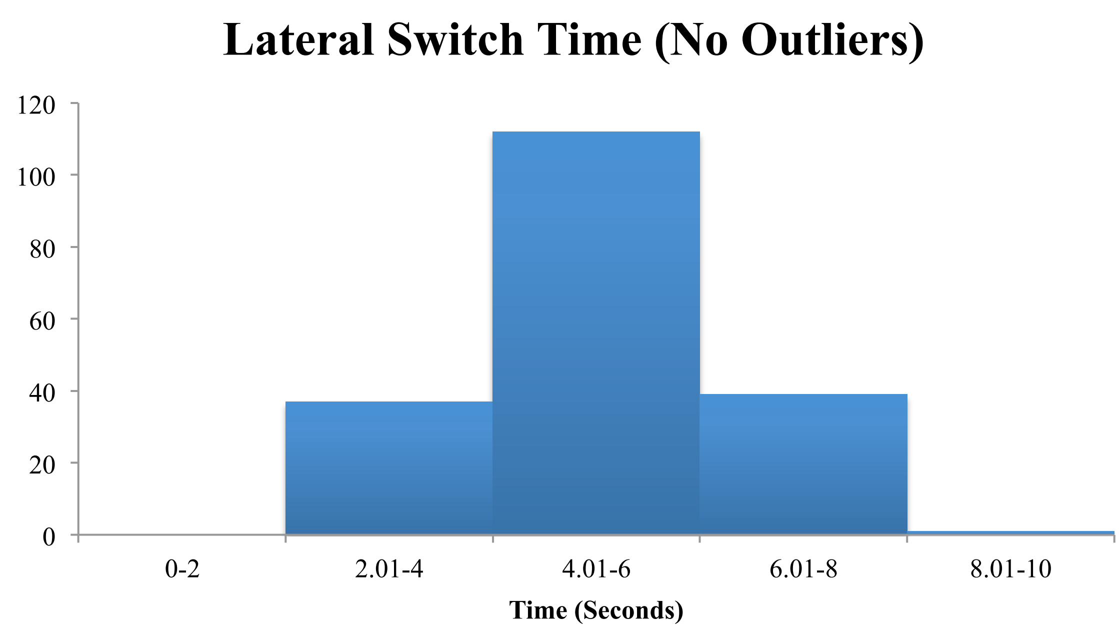

Figure 7. *Lateral switch times (outliers excluded)*

Hypotheses were tested using both the full and trimmed data. Descriptive statistics, intraclass correlation coefficients, and correlations among key study variables with and without outliers are presented in Table 4 and Table 5 respectively. The difference in data with outliers and without outliers is not the number of individuals (which remains at 52), but rather the number of switches for each type. With outliers included, there are 253 upward switches, 252 downward switches, and 205 lateral switches. After removing outliers, there are 239 upward, 224 downward, and 186 lateral switches. For all hypotheses, the first results will be those with outliers excluded, and then those with outliers included.

Table 4

Descriptive Statistics for Independent and Dependent Variables With Outliers Included

	N	Mean	SD	Min	Max	1	2	3	4
Task Switch Level									
1 Upward Switch Time	253	5.71	2.70	0.10	27.1	(0.49)			
2 Downward Switch Time	252	6.05	2.70	2.60	21.3	0.58	(0.26)		
3 Lateral Switch Time	205	5.71	3.74	2.90	52.1	0.71	0.56	(0.23)	
Individual Level									
4 Individual Mental Model Similarity With Teammates	52	0.35	0.15	0.12	0.769	-0.28	-0.36	-0.25	-

Note: ICC(1)s for individuals as the grouping variable are reported on the diagonal

Table 5

Descriptive Statistics for Independent and Dependent Variables With Outliers Excluded

	N	Mean	SD	Min	Max	1	2	3	4
Task Switch Level									
1 Upward Switch Time (seconds)	239	5.30	1.34	2.10	9.1	0.26			
2 Downward Switch Time (seconds)	224	5.28	1.33	2.60	8.8	0.65	0.10		
3 Lateral Switch Time (seconds)	186	5.04	3.74	2.90	7.9	0.71	0.69	0.31	
Individual Level									
4 Individual Mental Model Similarity With Teammates	52	0.35	0.15	0.12	0.77	-0.28	-0.34	-0.24	-

Note: ICC(1)s for individuals as the grouping variable are reported on the diagonal. Outliers were found and eliminated if they were 1.5 times above or below the interquartile range (IQR)

Hypothesis 1. Hypothesis 1 stated that shared mental model similarity would be positively associated with multiteam switch costs. This means that the more similar an individual's mental model is to his or her teammates, the longer it would take to make the switch from a team task to a multiteam task (upward switch). Table 6 shows that the impact of mental model similarity on upward switching is significant, but in the opposite direction $b = -1.610$, $t(50) = -2.010$, $p < .05$. This means that the more similar an individual's mental model is to his or her teammates the faster he or she is able to make the switch from a team task to a multiteam task. Specifically, with every standard deviation unit increase in mental model similarity with teammates, an individual's upward switch times decreases by 1.610 seconds. This negative effect was even stronger when outliers were included, $b = -3.642$, $t(50) = -2.123$, $p < .05$. Therefore, although the result is significant, it is in the opposite direction, and hypothesis 1 is not supported.

Hypothesis 2. Hypothesis 2 predicted shared mental model similarity would be negatively associated with team switch costs. This means that the more similar an individual's mental model is to his or her teammates, the shorter it would take to make the switch from a multiteam task to a team task (downward switch). Table 6 supports this hypothesis showing that the more similar an individual's mental model is to his or her teammates, the faster the switch time for downward switches, $b = -2.305$, $t(50) = -3.212$, $p < .05$. Specifically, with every standard deviation increase in mental model similarity with teammates an individual's downward switch time decreases by 2.305 seconds. This result with outliers included followed the same pattern as hypothesis 1 meaning that the negative effect was greater when outliers were included, $b = -4.556$, $t(50) = -3.223$, $p < .05$. Due to the higher ICC1 at the team level for downward switch times, analyses were also run using a 3-level model controlling for the individual and the team. The analyses using a 3-level model yielded the same result, $b = -2.346$, $t(17) = -2.88$, $p < .05$. While the effect of mental model similarity on switch time is more negative for downward switches compared to upward switches, the interaction effect is not significant, $b = -0.808$, $t(50) = -1.026$, $p > .05$.

Hypothesis 3. Hypothesis 3 stated that upward switching would incur greater switch costs than downward switching. This prediction means that, regardless of an individual's mental model similarity, it would take longer in general to switch from a team task to a multiteam task than it would to switch from a multiteam task to a team task. Examining the descriptives for data with outliers excluded in Table 6 shows that the mean downward switch time (Mean = 5.28 seconds) is hardly different than the mean upward switch time (Mean = 5.30 seconds). The multilevel analysis examining the effect of switch type on switch time while controlling for the individual was non significant, $b = -.04$, $t(50) = -0.35$, $p > .05$. With outliers, the sign changes, but the result is still non significant, $b = .325$, $t(50) = 1.565$, $p > .05$. Therefore, hypothesis 3 was not supported. There was not observed difference in the amount of time it took to make an upward relative to a downward switch.

Additional analysis. Although not hypothesized, for completeness the relationship between mental model similarity and lateral switching was examined as well. Lateral switches were when individuals switched from either of their team tasks to their other team task. These results are also found in Table 6. Multilevel analysis controlling for the individual showed that individual average mental model similarity was negatively related to lateral switch costs; this effect was significant at the .1 level, but not at the .05 level, $b = -1.431$, $t(50) = -1.92$, $p < .1$. This means that for every standard deviation unit increase in mental model similarity with teammates, an individual's lateral switch time decreases by 1.431 seconds. With the outliers included, there is no relation between mental model similarity and switch time, $b = -2.804$, $t(50)$

= -1.366, p > .1. Taken altogether, the results indicate that the more similar an individual's mental model is to his/her teammates, the faster he or she is able to switch between team and multiteam tasks.

Table 6

Individual Average Mental Model Similarity and Switch Times (N = 52)

	Individual Mental Model Similarity With Teammates (with outliers)				Individual Mental Model Similarity With Teammates (no outliers)			
DV	B	SE	t	df	B	SE	t	df
Upward Switch Time	-3.64	1.716	-2.123*	50	-1.610	0.801	-2.010*	50
Downward Switch Time	-4.556	1.414	-3.223*	50	-2.305	0.717	-3.212*	50
Lateral switch Time	-2.804	2.053	-1.366	50	-1.431	0.745	-1.92 †	50
	Switch Type (with outliers)				Switch Type (no outliers)			
Switch Type	0.325	0.208	1.565	50	-0.04	0.115	-0.35	50

Note. *the test statistic is significant at the alpha = .05 level. †The test statistic is significant at the .1 level.

Discussion

This thesis aimed to bring task switching into the world of teams. Previous research on task switching focused solely on how individuals switch between independent tasks (Wickens, Santamaria, & Sebok, 2013). This thesis examines how individuals switch between tasks that require varying levels of interdependence. When working on a team embedded in a complex system, it is not just the cognitive processes of the individual, but also the cognitive processes of the team that impact how easy it is to switch in and out of the various levels of interdependence.

I hypothesized that an individual's mental model similarity with teammates would make it take longer to switch from working with a team to working with a multiteam system. The reasoning was because an individual's mental model similarity with teammates would indicate how entrained he or she was with the team, and high levels of entrainment would make it difficult to break away from the team to focus on a multiteam task. The results contradict this claim, showing that higher mental model similarity with teammates makes it easier for an individual to switch from teamwork to multiteam work. I have considered a couple of explanations for this unexpected effect.

The first is because the tasks people were working on at the team level were similar in structure to the task at the multiteam level. The tasks were all the same sort of survival simulation ranking tasks so entrainment at the team level might not be as much of a barrier to switching since the tasks are similar. This could also explain why the effect was in fact significant and negative because, at that point, a higher degree of task mental model overlap with your teammates might translate smoothly to mental model overlap with members of other teams. This parallelism in tasks at different levels of interdependence is present in many real multiteam systems. The emergency response multiteam systems often engage in similar tasks as the component teams. Firefighters who go from setting up their equipment with their teammates to securing the perimeter working with the police are not engaging in vastly different tasks. What is relevant for the team task is also relevant when they move to the multiteam task.

A second possible explanation for the negative effect is because everyone on a team is performing the same switches at the same time. When an individual switches from the team task to work with the other team in the multiteam system, everyone else on the team is also switching to the multiteam task. In this way, an individual is never really breaking away from the team. An individual goes from working with his or her team on the team task to working with his or her team on the multiteam task with the other team. In other words, entrainment with a team might not mean entrainment on the team task, but rather entrainment to work done with teammates, in which case, higher average mental model similarity's negative effect on upward switch times is not as surprising. Entrainment could still be the mechanism at work in terms of enabling or hindering switching ability, but entrainment to the team would be enabling switching ability in both directions.

This second possible explanation would also be supported by the fact that the second hypothesis – that average mental model similarity would be negatively associated with downward switch times – was supported. Entrainment with the team would make it easier to switch with the team in either direction. The effect of average mental model similarity on downward switch times was slightly more negative (but not significantly so) than its effect on upward switch times. I would be cautious to interpret this result since it is not significant, but the trend could be hinting at the fact that there is a difference in teamwork and multiteam work when it comes to mental model similarity. That perhaps given a multiteam task vastly different from the team task, there would be a more stark difference in the effect of average mental model similarity on upward vs. downward switches.

Another possible cause for the similar findings for upward and downward switching is the operationalization of what a switch was. A switch was when an individual clicked on the tab of the appropriate task. However, in order to collaborate on a team task, individuals may not necessarily need to be clicked over to the team task tab. It's possible they could start communicating with each other even before they click the tab meaning they switch before the switch is registered on Morae. With the multiteam task, individuals had to switch tabs if they wanted to communicate with people on the other team. It's possible that individuals were cognizant of this need to quickly get over to the tab so they could speak to the other team and this urgency led to lower upward switch times. Also, individuals switching to a team task might switch much more quickly than is captured by Morae because they begin conversations about the task before switching tabs. Perhaps if faster switch times were captured for team tasks, an interaction could appear showing that mental model similarity had a greater impact on downward switch time than upward switch time. Related to this, team task is confounded with individuals being located in the same room and not needing technology to communicate, and multiteam task is confounded with teams being remote and needing technology to communicate. Therefore, instead of mental model similarity, there could be something about being remote that increases individuals' urgency to switch to that task thereby decreasing their switch time.

Finally, Hypothesis 3 predicted that, in general, downward switching would take less time than upward switching. This hypothesis was not supported, and this may be due to in part to the first explanation above. The team tasks and multiteam tasks were both the same sort of task with people working together to rank items in terms of importance in a survival situation. The team tasks were of course done with just a team focusing on their team goal, and the multiteam task was done with two teams focusing on their team goals while also attending to the multiteam system goal, but the work involved was very similar. In this case, the difference, or lack thereof, between upward switching and downward switching might have less to do with the change in interdependence not being a factor and more to do with the similarity of task work ameliorating the changes in interdependence.

In total, this thesis shows that an individual's average mental model similarity makes it easier to switch between team and multiteam tasks. There are some features of the study that may not perfectly resemble vertical task switching in real-world MTSs such as the fact that everyone on the team is switching to the same MTS task at the same time, and that the MTS and team tasks were similar in structure. In contrast, many real world teams may experience teammates switching independent of each other. For instance, on the International Space Station, three astronauts could be working together on a research task when one of them is called away by another group to assist with a maintenance task. Two astronauts remain on the research task while one switches to another team maintenance task. This example also illustrates the second point in that a maintenance task is not necessarily similar to a research tasks in terms of task elements and mental processes required. However that does not mean MTSs never exhibit this kind of behavior or engage in parallel tasks, but context will definitely play a role in the relationships this thesis reveals.

Implications

This thesis aimed to make two contributions. The first is to the literature on team effectiveness. Given that teams often work as a part of larger systems, this thesis shed light on the relations between upward and downward switches in interdependence on collective cognition. Very little is known about the process of making these vertical switches between team and multiteam tasks. An individual's ability to switch between these levels likely has an impact on the time it takes for them to get through the tasks, as well as the quality of the outcomes. Such understanding is also important for designing team tasks, and developing training and evaluation metrics in team settings. The second contribution is the literature on task switching. This thesis advances understanding of task switching by exploring costs that arise when individuals change the groups they are coordinating. This thesis also incorporates shared cognition and how an individual's mental model overlap with his or her teammates can enable easier switching between levels of interdependence.

As multiteam systems become more prevalent and necessary for tackling grand challenges such as a future mission to Mars, the knowledge gained from this thesis could be valuable when considering the schedule and interaction of astronaut teams with mission control teams. In high stakes situations such as space travel, when there comes a time when quick switches and coordination are required between mission control and crew, it is imperative that the crew be on the same page as each other, otherwise, one or more people may be slower to make the transition to between team work, which could result in information being missed or not shared at a crucial time. The same risk is true of any distributed system where coordinated switching between team and multiteam work is required. If one or more people are slower than others because their mental models are not in tune with the other members of the team, then this can cause the system to lag in order to catch the slower members up, and this efficiency lag can not only lead to errors or longer task times, but also to other people being frustrated and dissatisfied with the system as a whole.

Limitations

This was a highly controlled lab experiment meant to explore the effect of shared mental models on an individual's ability to make a forced switch. There are a number of important limitations that need to be considered. First, the level of control required for lab experiments like this typically comes at a cost of external validity. These participants were undergraduate students performing a short-term team task. They did not have the realistic relationships that accompany teams in field settings. For instance, the teams were assembled for the sole purpose of this experiment so the team members had no prior connections. Usually teams will be assembled from people that are part of the same department or people that have worked together in the past, and this was not the case for teams in this study. The teams also had not worked together in the past so there were no established relationships in the team and no expectations about how to work together. Teams in more realistic settings with more experience together might be able to switch between team tasks more easily compared to teams that are meeting for the first time, but the more realistic teams might also have more trouble breaking away from the team task to work on multiteam work compared to teams that are not as entrained to their team work.

Second, the findings may be specific to this type of task where the team and MTS task are highly similar and where members switch together. When a multiteam task switch was commanded, everyone on both teams switched to the multiteam task. Sometime people are working on a team and one or two people break off to coordinate with other teams in the multiteam system while other members stay on the team task, and even others might switch to another team task or work on individual projects. The pattern employed in this study may have amplified the negative effect of individual mental model similarity with teammates on switch times because being in sync with teammates might not facilitate as much (or could even hinder) when a person is not switching to a new task with his or her teammates. Therefore, the findings may not be generalizable to all team task switching. However, the situation of entire teams switching to work with other teams in a multiteam system is not unrealistic and does occur such as when so I think these results lend valuable insight into factors that effect making vertical task switches in interdependence. A possible solution to the pattern issue could be to have individuals start initially on different tasks (some on the team, some one the multiteam system, and some on the alternate team task). Then, instead of commanding individuals to switch to the same task, each individual could follow a unique pattern where sometimes everyone on a team is working on the same task, sometimes everyone is working on different tasks, and sometimes two are on one task while one is on another.

A third limitation to this study is that the manipulation of mental model similarity did not work as intended. The result was that analyses had to be performed modeling the relatively small amount of variation in mental model similarity. The mental model manipulation was intended to produce significant differences in similarity. Without this variation in mental models, this may have limited the power to detect effects on switch costs. It could be the case that mental model similarity improves upward task switching to a point, but individuals that are highly similar to their teammates do in fact struggle to break away from their teamwork. There were only three individuals who had individual mental model similarities with their teammates over .6 so the top end of the range was not very populated. The first hypothesis was that shared cognition was positively associated with multiteam switch costs. That might be supported for individuals with very high mental model similarity with teammates compared to low or moderate mental model similarity with teammates, but not supported for individuals with moderate compared to low mental model similarity with teammates. In order to detect this error, it would have been wise to pilot test the manipulation thoroughly before employing it in the study. The survival tasks were somewhat straightforward and easy to understand so individuals may not have needed to rely on the instructions telling them what strategy to use, and instead gone off of their own strategies. One possible solution would be to change how they view the survival task. For instance, some people would be told that finding food is the most important goal on the mission, while others are told, that signaling for help is the most important goal. This would change the way people looked at the items in terms of their priority, and perhaps more strongly alter the way they viewed the task. For instance, people with a focus on finding food, will be rating items based on how useful they are for hunting or trapping, while people focused on signaling for help are looking at the same items and thinking about how they can be used for a signal. In the end, these two conceptions of the items are very different compared to two people who have the same focus and viewpoint on the items.

A fourth limitation is that mental models were only measured once during the experiment and that was done after the end of the session. This approach, while it did capture an individual's final state, missed out on information about individuals' mental models at the beginning of the task. Mental models ideally should have been measured twice: once after training and once at the end of the session. This approach would have captured if the manipulation had an impact on mental model similarity at the beginning and the effect was simply washed out by the end of the task. This approach also would have captured if mental model evolution from start to finish had an impact on switch times so one could see if individuals who had greater mental model similarity increase also had a downward trend for switch times.

A fifth limitation is that there could be alternative explanations for why mental model similarity with teammates is negatively related to switch times. It could be the case that we are more cohesive with teammates when we are on the same page and being more cohesive makes it easier to switch tasks with them. In a team, there are many dynamic states and processes coevolving and impacting individuals' experiences. It might not be the case that mental model similarity is causing the decrease in switch time directly, but rather the effect is mediated by other team processes. In order to untangle the unique effect of mental model similarity, researchers would need to examine other team states and processes and control for other possible explanatory variables such as cohesion, conflict, coordination, team identity, etc.

Future directions

Future research is needed that explores the various task switching circumstances that arise in team and multiteam work. I think a major factor to include is switches from individual work to team and multiteam work and back. This thesis explored vertical task switching between the team and multiteam level, but in MTSs, people engage in all three levels of interdependence (individual, team and multiteam system). Individual work is different than the other two levels in that there is no interdependence so that could make it harder to make the downward switch from another level when an individual is highly entrained with his or her team.

Another important future direction is looking at different possible manipulations of mental models. There's research on mental models that uses some different manipulations like cross-training (Marks et al., 2002), interaction training or leadership briefings (Marks et al., 2000), but more research ought to be done that investigates these manipulations as well as new ones and matches them to different task types. For instance how can one best manipulate mental models in complex problem solving tasks, and does that strategy also work well for active tasks?

Similarly, the measurement of mental models should be examined in future research. Specifically, future research should detail the ways in which different methods for mental model elicitation are carried out. This thesis used pairwise comparison ratings as the method, and this was carried out using a matrix form (Appendix A), which shows a grid with items on the left and across the top and participants go through the grid comparing the item on the top to the item on the left. This process, while efficient may be confusing to people. Another possible approach would be to break down every comparison and present them as single questions. Instead of having a large matrix, they see several single comparisons that they then rate. This process is definitely easier to comprehend, but also has the potential to be very tedious. With 15 items to compare, an individual would have to go through 105 individual questions. These two approaches, while collecting the same information using the same method (pairwise comparison), would likely elicit vastly different responses. Future research should consider not just the method for measuring mental models, but also the procedure used to carry out that method.

Future work should also look at how mental models evolve over time and how that evolution changes the impact on switching ability over time. Especially in situations where a team is working together for days, weeks, or even years because mental models are bound to rise and fall, and the changes over the course of a long tenure could provide implications for when and how to schedule tasks. This thesis only assessed mental models once, and while that provides a good snapshot of the state of the team, there could have been times when individuals were very much in sync with their teammates making it harder in that moment to break away from teamwork to work with the multiteam system.

Finally, I think a next step forward is to investigate performance or team state implications of switching. As I mentioned previously, if a member of a team is slow to switch to multiteam work because they aren't as aligned with their teammates as everyone else, then this likely could have performance implications as well as an impact on how people feel about their team members.

Conclusion

Research on task switching has not previously considered individuals in the context of teams and multiteam systems. This thesis took an initial step in illustrating how team level cognitive properties may impact the speed at which individuals are able to shift from working in more to less interdependent tasks, and vise versa. These findings should encourage future task switching research to consider the contexts in which individuals are operating and stimulate future research on how individuals switch between team and multiteam system level tasks.

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Revised Content:

Appendix A

For this exercise, please rate the extent to which each pair of items are related in achieving the goals of your team:

1 = Totally Unrelated, 2 = Minimally related, 3 = Weakly related, 4 = Moderately related, 5 = Somewhat strongly related, 6 = Strongly related, 7 = Very strongly related

For instance, in the green box below you would indicate how related on a scale of 1-7 a shaving mirror is to a fishing kit in terms of achieving your team's goals:

	A shaving mirror	A fishing kit	Nylon rope	Shark repellant
A shaving mirror				
A fishing kit				
Nylon rope				
Shark repellant				

For your table, only fill in the boxes that are not greyed out.

Revised Content continued :

	A sextant	A shaving mirror	Mosquito netting	5 gallon can of water	A case of army rations	Maps of the ocean	Floating seat cushion
A sextant							
A shaving mirror							
Mosquito netting							
5 gallon can of water							
A case of army rations							
Maps of the ocean							
Floating seat cushion							