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Objective: We report an experiment in which three training approaches are compared with the goal of training adaptive teams. **Background:** Cross-training is an established method in which team members are trained with the goal of building shared knowledge. Perturbation training is a new method in which team interactions are constrained to provide new coordination experiences during task acquisition. These two approaches, and a more traditional procedural approach, are compared. **Method:** Assigned to three training conditions were 26 teams. Teams flew nine simulated uninhabited air vehicle missions; three were critical tests of the team's ability to adapt to novel situations. Team performance, response time to novel events, and shared knowledge were measured. **Results:** Perturbation-trained teams significantly outperformed teams in the other conditions in two out of three critical test missions. Cross-training resulted in significant increases in shared teamwork knowledge and highest mean performance in one critical test. Procedural training led to the least adaptive teams. **Conclusion:** Perturbation training allows teams to match coordination variability during training to demands for coordination variability during posttraining performance. Although cross-training has adaptive benefits, it is suggested that process-oriented approaches, such as perturbation training, can lead to more adaptive teams. **Application:** Perturbation training is amenable to simulation-based training, where perturbations provide interaction experiences that teams can transfer to novel, real-world situations.

INTRODUCTION

In settings ranging from business and manufacturing to military and medical operations, there are many tasks that are too cognitively demanding to be performed by individuals working alone. An example is a surgical task, which requires a set of highly trained individuals, including two surgeons, an anesthesiologist and two nurses, each of whom brings different cognitive capabilities to the team. But it is not enough to bring together a set of highly trained individuals. To function as a team, individuals must coordinate their activities. Adaptive teams have the ability to coordinate their activities not only under routine conditions but also under novel conditions for which they have not been explicitly trained. Adaptation is the altering of structure in accordance with changes in the environment. Because they have the ability to change their interactions to match the changing demands of the environment, adaptive teams can perform at a high level under novel task conditions.

A number of relatively recent tragic system failures can be at least partially attributed to poor coordination of a team-level response to environmental uncertainty. System failures attributable to poor team skills at Three Mile Island and Chernobyl (Gaddy & Wachtel, 1992), social pathogens behind the 1986 launch decision of the space shuttle Challenger (Vaughan, 1996), and lack of communication in the Operation Provide Comfort friendly fire incident (Gorman, Cooke, & Winner, 2006; Snook, 2002) each implicate, in different ways, deficiencies in interaction and coordination that result in a failure to adapt to changes in the task environment. These incidents, and others like them, highlight the need for training that addresses limitations and

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deficiencies at the team level in responding to novel patterns of events and threats.

Approaches to Training Adaptive Teams

A challenging problem for training team cognition (i.e., training teams to decide, plan, think, and act as an integrated unit; Cooke, Gorman, & Winner, 2007) is how to balance training for high performance under routine task conditions with training to adapt to novel task demands (Marks, Zaccaro, & Mathieu, 2000; Stachowski, Kaplan, & Waller, 2009). These training goals can be approached with varying theoretical motives. In this article, we report an experiment in which three training approaches, each with a different underlying theoretical motive, were investigated with the goal of training teams that perform at a high level under novel task conditions. The training approaches include cross-training, procedural training, and perturbation training.

Cross-training. In cross-training, team members are trained on each other's roles and responsibilities (e.g., Blickensderfer, Cannon-Bowers, & Salas, 1998). Cross-training is theoretically aligned with the idea that team cognition is the shared knowledge of the team members and is found widely in the team training literature (see Salas et al., 2008, and Salas, Nichols, & Driskell, 2007, for recent meta-analyses). The goal of cross-training is the development of shared, or interpositional, knowledge (Cannon-Bowers, Salas, Blickensderfer, & Bowers, 1998; Cooke et al., 2003; Volpe, Cannon-Bowers, Salas, & Spector, 1996). Positional clarification (receiving information on other roles), positional modeling (observing other roles), and positional rotation (firsthand experience performing different roles) (Blickensderfer et al., 1998), which are types of cross-training, have been effective in the development of shared knowledge, ultimately improving coordination and team performance (e.g., Marks, Sabella, Burke, & Zacarro, 2002). Cross-training has a firm empirical grounding and a record of success in the team training literature, making it a good point of comparison with the other approaches in this study.

One of the potential benefits of cross-training for shared knowledge is a high level of team performance under stress (high workload, time pressure). Drawing on shared knowledge, team members anticipate each other's needs to communicate efficiently, or coordinate implicitly, under stress (Cannon-Bowers et al., 1998; Entin & Serfaty, 1999; Stout, Cannon-Bowers, Salas, & Milanovich, 1999). It is thought that shared expectations, resulting from the development of shared knowledge, allow team members to generate predictions for appropriate behavior under novel conditions, enabling them to quickly adapt to the changing demands of the task environment (Fiore, Salas, & Cannon-Bowers, 2001). A possible drawback of a shared set of expectations, however, is the habituation of team member interaction, which could result in dysfunctional consequences if the situation is highly novel (e.g., Gersick & Hackman, 1990; Gorman, Cooke, & Winner, 2006).

Whereas cross-training is feasible for relatively small, homogeneously skilled teams, it can become impractical as teams grow in diversity and size. For example, it would be impractical to cross-train the surgeon and nurse positions of an emergency room team (Cooke et al., 2003; Marks et al., 2002). Also, cross-training may negatively impact individual-level performance due to the demands of training for multiple team member roles (Cannon-Bowers et al., 1998), which is problematic as teams grow in size. Although there are adaptive benefits of cross-training, there are practical limitations to its applicability.

Procedural training. Procedural training is a form of process training in which operators in complex systems are positively reinforced (through feedback) to follow a standard sequence of actions (a procedure) each time a particular stimulus is encountered. The assumption behind procedural training is that if the procedure is always followed, then errors resulting from human interaction will be reduced and performance will be enhanced, particularly under conditions of stress and high workload (e.g., Hockey, Sauer, & Wastell, 2007; Sauer, Burkholter, Kluge, Ritzmann, & Schuler, 2008). Procedural training is widely used in aviation, military, medical, manufacturing, and business settings, in which deviations from complicated procedures can be catastrophic. The prevalence of procedural training for coordination in highly critical team tasks (e.g., emergency response; Ford & Schmidt, 2000; Stachowski et al., 2009) make it a good point of comparison for the other training methods in this study.

Procedural training is compatible with the concept of "overlearning": continuation of practice beyond mastery that leads to automatic responding. Drilling a standard team interaction pattern, for a specific class of event, over the entirety of training can lead to an automatic response that a team can rely on under stress. The goal of procedural training, as operationalized in the current study, is to overlearn a team coordination procedure. Ideally, due to overlearning, procedurally trained teams perform under stress by automatically (reflexively) reacting with an a priori coordinated response.

Procedural training does not impose the practical limitations of cross-training but may limit a team's ability to transfer training to novel situations. Similar to the concept of a "set effect" (Luchins, 1942), procedural training may set teams up to coordinate in a routine fashion under a novel condition. We argue, therefore, that like habituation (Gersick & Hackman, 1990), rigid proceedure-following during task acquisition can lead to poor performance when posttraining conditions do not match training conditions.

Perturbation training. Perturbation training is a form of process training introduced in this study. Adopted from the dynamic systems literature, a perturbation is an extrinsic application of force that briefly disrupts a dynamic process, forcing the reacquisition of a new stable trajectory, and is typically used to probe the stability of that process (Gorman, Amazeen, & Cooke, in press). The concept of perturbation can be applied to team training by disrupting standard coordination procedures multiple times during task acquisition, forcing teams to coordinate in novel ways to achieve their objective. Unlike training in which the situation or objectives are varied (e.g., training for low- vs. high-frequency circumstances), in perturbation training, critical coordination links are disrupted while the team objective remains constant. The goal of perturbation training is to counteract habituation and procedural rigidity associated with team interactions—possible outcomes of cross-training and procedural training, respectively—allowing teams to acquire flexible interaction processes that will transfer to novel task conditions.

Perturbation training is theoretically inspired by findings in the motor- and verbal-learning literatures that suggest that introducing difficulties for the learner, such as practice condition variability, facilitates performance under novel posttraining conditions (Schmidt & Bjork, 1992). Perturbation training thus shares some features of motor schema theory (Schmidt, 1975) and desirable difficulties (Bjork, 1994) but for coordination and for teams. According to motor schema theory, varying the conditions of practice during motor skill acquisition enhances the "rules" that relate movements to external task demands. In verbal learning, desirable difficulties are unpredictable and variable conditions of practice that cause difficulty for the learner but ultimately enhance the transfer of concepts to new contexts. Whereas those approaches employ equally probable but randomly varying training conditions to introduce practice condition variability, perturbation training employs abrupt but focused disruptions to team coordination.

Bjork (1994) argued that varying practice conditions exercises more elaborate encoding and retrieval processes needed in the posttraining environment. Perturbation training extends this idea to team process: When coordination is perturbed, all team member interactions (not just those directly affected by the perturbation) must readjust to accommodate the perturbation in such a manner that the team objective is nevertheless met (Turvey, 1990). We suggest that similar to the effects of practice condition variability, perturbations exercise the team processes needed to adapt in the posttraining environment.

A major limitation of perturbation training is that it has not previously been applied and its effectiveness is unknown. An experiment described by Gorman, Cooke, Pedersen, et al. (2006) provided some empirical grounding for perturbation training. Teams were initially trained and performed a repetitive command-and-control task during a 3-hr experimental session. Participants returned for a second session after a retention interval, after which they were either intact (kept the same team members) or mixed (same role on the team but different team members).

As expected, intact teams outperformed mixed teams under routine conditions, but the effect was short-lived. Mixed teams, however, performed better on tests of situation awareness, had higher process ratings (Gorman, Cooke, Pedersen, et al., 2006), and had more flexible coordination dynamics (Gorman et al., in press). Those benefits were not attributable to increased shared knowledge or procedural rigidity but to increased variation in interaction experience.

In some sense, mixing up the team members *perturbed* rigid coordination patterns, ultimately leading to a more flexible and adaptive team. Perturbation training, as operationalized in the current study, does not involve mixing team members but was designed have the same effect. By disrupting standard coordination procedures during task acquisition, perturbation training increases interaction experience in intact command-and-control teams.

The Current Study

We compared the three different training approaches in an uninhabited air vehicle (UAV) simulator with the goal of producing teams that perform at a high level under novel task conditions and that respond rapidly to novel events. In the UAV task, three team members (navigator, photographer, and pilot) coordinate to take pictures of stationary ground targets. Three training protocols were developed for cross-training, perturbation training, and procedural training of UAV teams. The following hypotheses are based on prior results and existing literature.

Hypothesis 1: By focusing on introducing varied interaction experiences during task acquisition, perturbation training will result in performance scores and response times to novel events that are as good as or better than cross-training and superior to procedural training.

Hypothesis 2: Because of its focus on training team members to know each other's roles and responsibilities, cross-training will result in higher levels of shared knowledge compared with both procedural and perturbation training.

Hypothesis 3: By training teams to rigidly follow a procedure, procedural training will result in the least adaptive teams (i.e., poor performance and slow response to novel events) compared with both perturbation and cross-training.

METHOD

Participants

We recruited 32 three-person teams (96 participants) for participation from Mesa, Arizona, and surrounding areas. The team members had no prior experience working together. Participants ranged in age from 18 to 54 (M = 28), and 71 were male. The experiment occurred during two 3- to 4-hr sessions. Because of scheduling conflicts for Session 2, a total of 26 teams (78 participants) completed both experimental sessions. Participants were paid $10 per hour, and each member of the highest-performing team received a $100 bonus.

Materials and Apparatus

The experiment was conducted in a UAV synthetic task environment (UAV-STE) for teams (Cooke & Shope, 2005). Each of the three team members was seated at a workstation in front of three computer monitors with a keyboard and a mouse. To interact, team members wore aviation-quality headsets and communicated by holding down push-to-talk buttons. The workstations were located in the same room, configured in a *U* shape with team members backs to each other. With the team members donning headsets, the UAV-STE did not afford face-to-face interaction.

The team's task was to take reconnaissance photographs of stationary ground targets during a series of nine 40-min missions divided across two experimental sessions. There were 11 to 12 targets per mission except for one high-workload mission that had 20 targets. The three team member roles—navigator, photographer, and pilot—were each associated with different, yet interdependent tasks, information resources, and needs.

Measures

Team performance. Performance was measured for each UAV-STE mission as the weighted composite of several team-level mission parameters, including number of missed targets, time to process targets, and time spent with unaddressed warnings and alarms. Cooke, Gorman, Pedersen, et al. (2007) report the parameter weights, which were established in previous experiments to maximize score sensitivity. Teams started each mission with a performance score of 1,000, and points were subtracted on the basis of final values of the mission parameters. This team performance score has been validated against other measures of team process and performance (Cooke, Gorman, Duran, & Taylor, 2007; Cooke, Gorman, Pedersen, et al., 2007).

Response time to novel events. Novel events were introduced within UAV missions by introducing roadblocks. Roadblocks are novel changes in the task environment that have to be jointly recognized by two or more team members who take action to overcome them (e.g., a new target is introduced, equipment fails, an enemy threat appears; Cooke, Gorman, & Rowe, 2009; Gorman, Cooke, & Winner, 2006). Time to overcome roadblocks, defined as the time from the initiation of the roadblock to the time that action is taken that overcomes the roadblock, was the measure of response time to novel events.

Interpositional taskwork knowledge. This measure assessed a team's average knowledge of the taskwork associated with the other two roles. To measure taskwork knowledge, relatedness ratings (1 = *completely unrelated* to 5 = *completely related*) were elicited for 55 pairs of concepts from the UAV task (e.g., airspeed, altitude). Individual team member ratings were analyzed using the Pathfinder algorithm (Schvaneveldt, 1990), which translates relatedness ratings across pairs of concepts into a graphical network representation of conceptual interrelatedness.

Individual networks were compared with expert role referent networks. The referents were derived empirically from the top five individual performers at each role in previous UAV-STE experiments (Cooke, Gorman, Pedersen, et al., 2007). Each team member was scored against the other two role referents on the basis of the proportion of shared links (0 = *no similarity* to 1 = *exactly similar*). Team-level interpositional taskwork knowledge was taken as the average of these two scores across each of the three team members. Scores closer to 1 indicated a higher level of interpositional taskwork knowledge across team members.

Interpositional teamwork knowledge. This measure assessed a team's average knowledge of the teamwork associated with the other two roles. Interpositional teamwork knowledge was elicited with the use of a questionnaire that consisted of 16 items related to which communications were necessary to achieve a given scenario goal (e.g., "For a priority target, must the photographer communicate camera settings to the navigator, the pilot, or both?"). Items that were necessary had to be indicated by individual team members using check marks. To calculate teamwork knowledge, individual responses were compared with role-specific answer keys that were generated by experimenters familiar with the task, and points were awarded for correct answers (Cooke, Gorman, Pedersen, et al., 2007).

To measure interpositional teamwork knowledge, each team member was scored on the basis of the proportion correct relative to the answer key for each of the other two roles. Interpositional teamwork knowledge was calculated as the average number of these two scores across the three team members. Scores closer to 1 indicated a higher level of interpositional teamwork knowledge across team members.

Procedure

When participants arrived for the first session, they were randomly assigned to a team member role and the team was assigned to one of the three training conditions. Participants received approximately 1 hr 45 min of training via three PowerPoint training modules and a hands-on training mission. The first two PowerPoint modules were identical for all training conditions and covered the general task and interface. The third module and the hands-on training mission differed on the basis of training condition. (Procedures for each training condition are described in the following section.)

Teams then completed Missions 1 through 5. Knowledge measures were taken after Mission 1. Missions 2 through 4 were condition-specific training missions (Table 1). The first roadblock was introduced during Mission 5, the first post-training mission. The roadblock consisted of cutting communication from the navigator to the pilot for 5 min, during which teams had to reroute navigator-to-pilot communications through the photographer to overcome the roadblock. Mission 5 was the first of three critical missions that tested the teams' ability to perform under novel conditions. The completion of Mission 5 concluded the first session.

TABLE 1: Experimental Procedure

Session 1	Session 2
Initial participant training	Refresher training
Mission 1	Mission 6 (retention test and second roadblock)^{C}
Knowledge measures	Knowledge measures
Mission 2^{T}	Mission 7
Mission 3^{T}	Mission 8
Mission 4^{T}	Mission 9 (high workload and two-part roadblock)^{C}
Mission 5 (first roadblock)^{C}	Debriefing

Note. T = condition-specific training mission; C = critical test mission.

Teams returned after 8 to 10 weeks for the second session. All participants received refresher training on the software interfaces, after which teams completed four additional UAV-STE missions. Roadblocks were introduced during each mission. Mission 6 was the second critical mission, which tested retention of team skill after the break and included the second roadblock (a disguised target was hidden on the navigator map and photographer target list; teams had to recognize and photograph the target to overcome the roadblock). Knowledge was measured for a second time after Mission 6 as a test of knowledge retention.

Teams then completed their final three missions (Missions 7 through 9). Mission 9 was the high-workload mission, in which the rate of targets per minute was almost doubled from 0.28 to 0.5 and teams were exposed to a two-part roadblock (communication channel cut for 5 min from pilot to navigator and from navigator to pilot; teams had to reroute their communications through open channels to overcome the roadblock). Mission 9 was the third of the three critical test missions.

Training Procedure

Cross-training. For the third PowerPoint training module, team members in the cross-training condition received training on the other two roles (positional clarification). Teams then completed a short training mission followed by approximately 15 min of hands-on experience performing all team member roles (positional rotation). After Missions 2 through 4, teams in the cross-training condition were prompted to discuss how well they performed and to plan for the next mission.

Procedural training. For the third PowerPoint training module, teams in the procedural training condition received training on the standard UAV-STE target photographing procedure: (a) The navigator provides target information to the pilot, (b) the pilot and photographer negotiate altitude and airspeed for that target, and (c) the photographer provides feedback on the status of the target photograph (Figure 1). Teams then completed a short training mission followed by approximately 15 min of hands-on training using the target photographing procedure. After Missions 2 through 4, teams in the procedural condition received experimenter feedback on deviations from the standard procedure. During training, team members in the procedural condition were provided with a hard copy of the target photographing procedure.

Perturbation training. Teams in the perturbation training condition received filler PowerPoint training on the history and current uses of UAVs. Teams then completed a short training mission followed by approximately 15 min of communications system testing in which they identified the source of static in the UAV-STE communication system (i.e., which push-to-talk button was emanating static). This training exercise provided experience on the use of multiple communication paths. During Missions 2 through 4, teams in the perturbation condition received perturbations to the target-photographing procedure (Table 2) as they attempted to photograph targets. Perturbations were less general than roadblocks and forced teams to adjust specific interactions

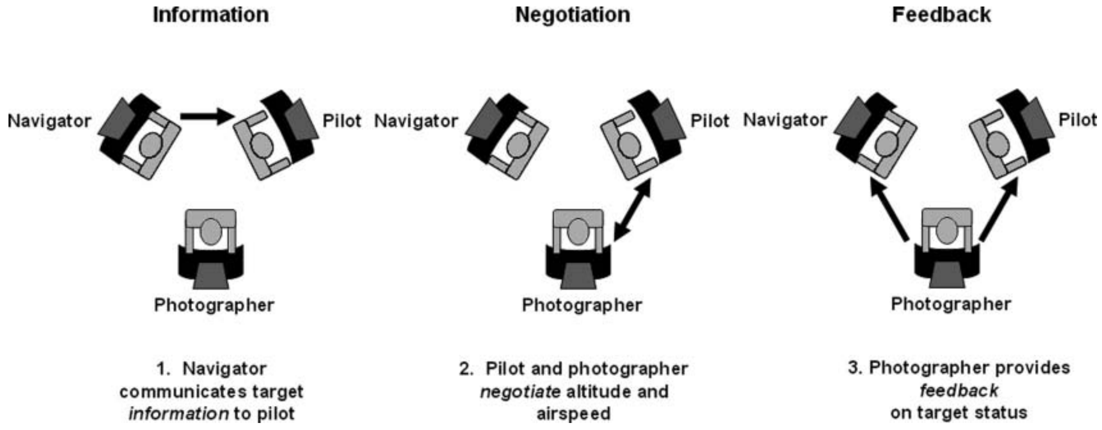

Figure 1. Standard photographing procedure for the uninhabited air vehicle synthetic task environment.

TABLE 2: Perturbations to the Standard Uninhabited Air Vehicle Synthetic Task Environment Target-Photographing Procedure Used for Perturbation Training During Missions 2 Through 4

Link in the Procedure	Perturbation	Method of Introducing Perturbation	When Introduced
Information	Photographer must provide target information to pilot	Experimenter calls in new target restrictions to photographer and disables camera until restrictions are communicated to pilot	Once in Mission 2 Once in Mission 3 Twice in Mission 4
Negotiation	Navigator/pilot must negotiate airspeed/altitude	Experimenter calls in new airspeed/altitude of current target to navigator	Once in Mission 2 Once in Mission 3 Twice in Mission 4
Feedback	Photographer does not provide feedback to navigator and pilot	Experimenter calls in status of target photo to navigator and pilot and cuts all photographer communications	Once in Mission 2 Twice in Mission 3 Twice in Mission 4

relative to the information-negotiation-feedback procedure (Figure 1).

RESULTS

Of the 26 teams that completed the experiment, there were 10 teams in the procedural condition and 8 teams each in the cross-training and perturbation conditions. Previous experiments in the UAV-STE exhibited low between-subjects power with $\alpha = .05$ ($M = .11$, $SD = .05$) on tests of team performance due to small sample size. To increase statistical power, a significance level of $\alpha = .10$ was used. For planned critical test mission comparisons, two conditions were pooled to form a comparison against a single condition. These planned comparisons also served to increase power.

Team Performance

Team performance results are summarized in Table 3 and graphed in Figure 2. Team performance was analyzed using a 3 (training) × 9 (mission) mixed ANOVA. The main effect of mission was significant, $F(8, 184) = 22.14$, $p < .001$, $MSE = 3535.25$, $\eta^2 = .53$. No other effects in the omnibus test were significant. A repeated contrast on mission revealed that performance increased significantly during initial performance acquisition until Mission 4. There was a significant drop in performance at Mission 6, after the retention interval. Performance then improved significantly as teams reacquired the task, until Mission 8. Task reacquisition was followed by a significant drop in performance at Mission 9, the high-workload mission. These results reinforce Missions 5, 6, and 9 as critical missions.

TABLE 3: Mean Team Performance by Training Condition

Mission	Cross-Trained	Perturbation	Procedural
1	345.04 (65.80)	342.78 (54.23)	316.92 (78.88)
2	383.18 (72.89)	409.33 (80.94)	373.90 (65.65)
3	422.58 (74.39)	463.39 (80.69)	439.92 (54.71)
4	450.54 (77.71)	483.76 (59.83)	447.83 (54.26)
5	446.40 (64.41)	500.37 (50.93)*	469.63 (46.92)
6	435.99 (54.48)	380.30 (166.10)	383.76 (100.91)
7	477.79 (77.32)	471.77 (75.38)	421.38 (86.88)
8	513.25 (70.94)	547.06 (47.86)	502.47 (58.60)
9	389.13 (76.39)	442.24 (36.83)*	372.02 (46.00)

Note. Standard deviations in parentheses.
*$p < .10$.

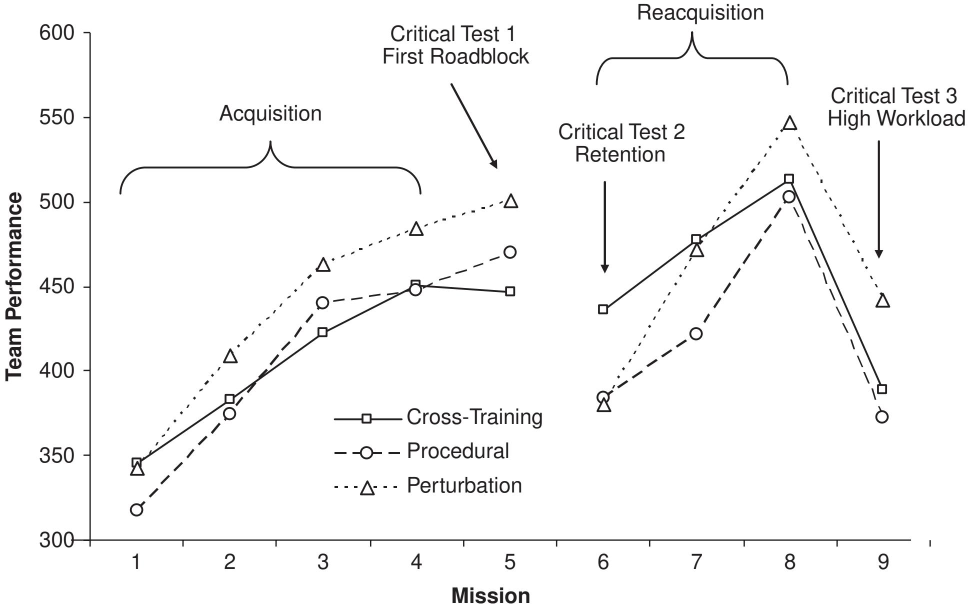

Figure 2. Team performance for each training condition across missions. Adapted from Gorman et al. (2007).

Planned comparisons were performed for each of the three critical test missions to address which training condition resulted in the highest performance under novel conditions. As shown in Figure 2, perturbation-trained teams exhibited better mean performance in two of the three critical test missions (Missions 5 and 9), whereas cross-trained teams exhibited better mean performance in one of the critical test missions (Mission 6). Performance of the perturbation-trained teams at Mission 5 (M = 500.37, $SD = 50.93$) was significantly better than the other two conditions (M = 459.31, SD = 54.91), $F(1, 24) = 3.23$, $p = .085$, $MSE = 2892.21$, $\eta^2 = .12$. Performance of perturbation-trained teams at Mission 9 ($M = 442.24$, $SD = 36.83$) was also significantly better than the other two conditions ($M = 379.62$, $SD = 60.00$), $F(1, 24) = 7.37$, $p = .012$, $MSE = 2945.49$, $\eta^2 = .24$. The cross-training performance advantage at Mission 6 was not significant, $F(1, 24) = .76$, $p = .392$, MSE = 8379.75, $\eta^2 = .03$.

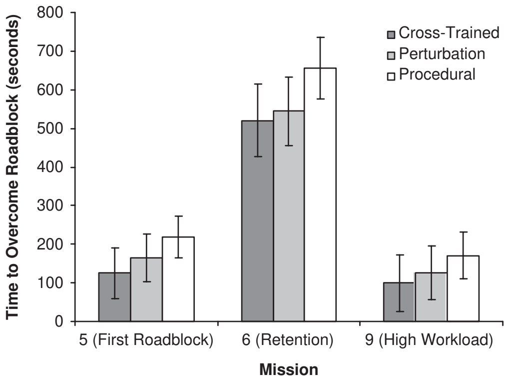

Figure 3. Time to overcome roadblocks by training condition across the critical missions (error bars represent 90% confidence intervals).

Response Time to Novel Events

Time to overcome roadblocks was analyzed with a 3 (training) × 3 (critical mission) mixed ANOVA. One observation was missing from the cross-training condition. There was a significant main effect of mission, $F(1.53, 33.59) = 119.82$, $p < .001$, $MSE = 16018.63$, $\eta^2 = .85$ (Greenhouse-Geisser correction used). The significant mission effect was attributed to differences in the difficulty of roadblocks. Therefore, no further analyses were performed to isolate that effect. The main effect of training was also significant, $F(2, 22) = 3.53$, $p = .047$, $MSE = 19460.72$, $\eta^2 = .24$ (Figure 3).

The planned comparisons at the critical missions revealed that procedural-trained teams were significantly slower to overcome roadblocks ($M = 218.70$, $SD = 94.34$) than were teams in the other two conditions ($M = 146.67$, $SD = 103.52$) at Mission 5, $F(1, 23) = 3.11$, $p = .091$, $MSE = 10005.89$, $\eta^2 = .12$. Teams with procedural training were also significantly slower ($M = 656.00$, $SD = 191.01$) than those in the other two conditions ($M = 533.07$, $SD = 98.35$) at Mission 6, $F(1, 23) = 4.50$, $p = .045$, $MSE = 20164.71$, $\eta^2 = .16$. The same comparison at Mission 9 was not significant. The Training × Critical Mission interaction was not significant. Analysis of the measure for time to overcome roadblock in the noncritical missions (i.e., Missions 7 and 8) did not reveal any significant differences.

Interpositional Knowledge

Interpositional teamwork and taskwork knowledge results are summarized in Table 4. Interpositional teamwork and taskwork knowledge were separately analyzed with 3 (training) × 2 (session) mixed ANOVAs. The taskwork ANOVA did not reveal any significant differences. There was a significant interaction effect for interpositional teamwork knowledge, $F(2, 23) = 2.70$, $p = .089$, $MSE = .01$, $\eta^2 = .19$ (Figure 4). Pooled comparisons revealed that cross-training ($M = .87$, $SD = .07$) led to significantly higher interpositional teamwork knowledge compared with the other two conditions ($M = .78$, $SD = .08$) at Session 2, $F(1, 24) = 7.04$, $p = .014$, $MSE = .01$, $\eta^2 = .23$. The same comparison for Session 1 was not significant. The main effect of session for interpositional teamwork knowledge was also significant, $F(1, 23) = 6.24$, $p = .02$, $MSE = .01$, $\eta^2 = .21$. Although teams in all training conditions exhibited some increase in interpositional teamwork knowledge across sessions, teams in the cross-training condition exhibited a significantly greater increase.

DISCUSSION

Perturbation-trained teams significantly outperformed teams in the other conditions in two out of three critical test missions, and their response times to overcome novel roadblock events were roughly equivalent to cross-trained teams. These results lend support to our first hypothesis that perturbation training leads to high performance under novel conditions.

The results suggest that something similar to the effects of practice condition variability (Schmidt & Bjork, 1992) contributed to transfer at the team level: Perturbation training allowed teams to generalize performance to novel conditions by forcing the teams to coordinate in new ways during task acquisition. However, whereas practice condition variability provides a range of task conditions for the individual learner, perturbation training induced coordination variability across team members during repetitions of the same task. By training teams to formulate and test new solutions to the problem of coordinating ground targets during task acquisition, perturbation training actively engaged

TABLE 4: Mean Interpositional Teamwork and Taskwork Knowledge by Training Condition

Measure	Cross-Trained	Perturbation	Procedural
Teamwork			
Session 1	.73 (.12)	.78 (.12)	.74 (.11)
Session 2	.87 (.07)*	.79 (.06)	.77 (.09)
Taskwork			
Session 1	.47 (.04)	.46 (.05)	.48 (.05)
Session 2	.47 (.01)	.48 (.04)	.48 (.03)

Note. Standard deviations in parentheses.
*$p < .10$.

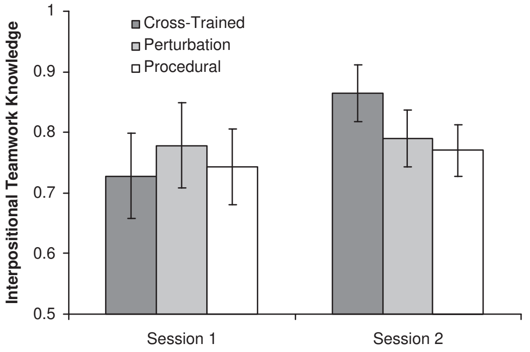

Figure 4. Interpositional teamwork knowledge by training condition across knowledge measurement sessions (error bars represent 90% confidence intervals).

team processes that are needed to adapt to novel, but related, coordination problems in the posttraining environment. Because perturbation training builds on prior novelty, it may also have allowed teams to develop within a rich experiential learning environment (Kolb, 1984).

Our second hypothesis was that cross-training would result in the highest levels of shared knowledge but that this would not necessarily result in the best performance under novel task conditions or the fastest response times to novel events. Support for that hypothesis was mixed. Cross-training resulted in greater shared teamwork knowledge in the second session but not in the first session. This is not a surprise given that the majority of condition-specific training took place after the first knowledge measurement session. However, shared taskwork knowledge did not change across experimental sessions, regardless of training condition. This may suggest a ceiling effect, such that task-related concept relatedness (e.g., the association between airspeed and altitude) does not change after initial participant training.

Cross-training also resulted in highest mean performance at one of the critical missions (the retention test) and faster response times for overcoming roadblocks, although those differences were not significant. It is possible that with a larger sample size, or a less variable task environment, cross-training would have resulted in significant advantages. Marks et al. (2000) found that development of a shared mental model predicted performance under novel task conditions better than under routine task conditions. The retention and roadblock tests are novel conditions unique to our experiment, however, and further empirical work is needed to better understand the benefits of cross-training and shared knowledge under these conditions.

The results support our third hypothesis that procedural training should result in the least adaptive teams. Procedural training is arguably the most prevalent form of training for coordinating highly critical team tasks, but its utility for training adaptive teams has been increasingly called into question (e.g., Ford & Schmidt, 2000; Grote, Kolbe, Zala-Mezö, Bienefeld-Seall, & Künzle, 2010; Stachowski et al., 2009).

Procedural training need not be limited to a single, standardized coordination process; assuming that the space of possible future events is finite, procedures can be scripted for a variety of foreseeable contingencies. Nevertheless, given the current results, we argue that teams trained to automatically follow a standardized coordination procedure become rigid and slow to adapt to novel changes in highly dynamic task environments. Whereas proceduralization may be good for unchanging and foreseeable aspects of a task, in training adaptive teams, there should be a match between interaction variability and the changing dynamics of the task environment.

We examined team performance under three critical situations: adaptation to a novel event (roadblock), after a retention interval, and under high workload. This is not an exhaustive list of possibilities. There are many forms of adaptation for which a team could be trained (e.g., role structure adaptation; Lepine, 2005). The current results are intuitively plausible, however, given the nature of mechanisms of team adaptation currently found in the adaptive team literature, and extend the idea of process-based adaptability training. The building and maintenance of shared mental models are thought to support team adaptation (Burke, Stagl, Salas, Pierce, & Kendall, 2006; Stout et al., 1999; Waller, Gupta, & Giambatista, 2004). Indeed, cross-training was successful in building shared teamwork knowledge, and cross-trained teams exhibited potential for high performance under novel conditions. Parallel to the motivation for perturbation training, however, teams directly adapt via flexible interaction processes (Gorman et al., in press; Manser, Harrison, Gaba, & Howard, 2009; Stachowski et al., 2009; Waller, 1999). Kozlowski, Gully, Nason, and Smith (1999) suggested that teams adapt by selecting an appropriate form of interaction from a preexisting repertoire or by creating a new form. Approaches like perturbation training have the potential to broaden a team's interaction repertoire not by prescribing preexisting forms of coordination but by allowing teams to exercise bottom-up organization of new coordination links.

What are the practical implications for training adaptive teams, and how can we apply perturbation training? Simulation-based team training (Dorsey et al., 2009) would allow for the design of perturbations that focus on specific events, times, or interactions (Gorman, Cooke, & Duran, 2009). Simulation-based training can emphasize physical (equipment) fidelity or cognitive fidelity (how well the simulation exercises psychological processes required for that task; Goettle, Ashworth, & Chaiken, 2007). For perturbation training, cognitive fidelity should be emphasized in order to exercise the team interaction processes needed for the real-world task (Bowers & Jentsch, 2001). Another concern is the specifics of introducing perturbations: when, how many, what kind, and how often? Simulation-based training would be the ideal venue for perturbation training, and although approaches such as crew resource management (see Salas, Wilson, Burke, & Wightman, 2006) may use simulators to train for rare or novel events, our results suggest that more thought and research should go into identifying the types of team interaction experiences needed and the ideal timing of those experiences.

What are the implications of the varying theoretical training motives—shared knowledge, proceduralization, flexible interactions—for team cognition? Prevalent in the team cognition literature is a distinction between knowledge and process and which contributes most to team effectiveness (e.g., Cooke, Gorman, & Winner, 2007). We submit that cross-training most directly impacts knowledge, that perturbation training most directly impacts process, and that procedural training may have little impact on either. The current study is not an unequivocal test of knowledge versus process accounts of team cognition, nor is it an exhaustive sampling of variations on procedural, perturbation, or cross-training in a variety of contexts. Nonetheless, the results do suggest that training focused on process may contribute something to team effectiveness that a knowledge-focused approach does not.

CONCLUSION

The details of team adaptation are not specified at the outset of a novel event. The details accrue gradually, during the process of adaptation, and there lies the problem for training adaptive teams: They must be able to decide, plan, think, and act under conditions never experienced. Adaptation is the altering of structure in accordance with environmental change and, under many circumstances, is not a purely top-down, knowledge-driven process. Teams should be provided opportunities to exercise adaptive competency using not only top-down (knowledge-focused) training but also bottom-up (process-oriented) training. Perturbing coordination as team members interact is one means of eliciting the bottom-up, process-oriented flexibility that teams need in order to adapt. Future research should continue to explore mechanisms of flexible team interaction and how teams use them to adapt to the pressures of highly dynamic, high-stakes work environments.

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