

CULTURAL DIFFERENCES IN SITUATIONAL AWARENESS, SHARED MENTAL MODEL, AND WORKLOAD PERCEPTIONS: AN ANALYSIS OF AMERICAN AND CHINESE SIMULATED FLIGHTCREWS

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Human error is responsible for most aircraft accidents. Many of these errors can be traced to ineffective team behaviors and processes in the cockpit. Crew resource management (CRM) seeks to redress poor flightcrew performance by training pilots and copilots to work effectively as a team. While CRM has been effective in the US in reducing the number of aircraft accidents, it may not be generalizable to other cultures. Specifically, values of other cultures may conflict with CRM ideology, which is steeped in Western values. This study examined the influence of national culture on three team behaviors—situational awareness, shared mental model, and workload perceptions—in 149 simulated flightcrews. Chinese and American male graduate and undergraduate students were divided into homogeneous (i.e., single culture Chinese or single culture American) and heterogeneous (i.e., Chinese and American) teams. Results show significant differences in situational awareness and physical workload perceptions across the three experimental conditions. However, there were no significant differences in shared mental model and other workload perceptions across the three team types. Measures of cultural values failed to explain differences situational awareness, shared mental model, and workload perceptions. Limitations of the current research design are discussed, along with directions for future study of cultural influences on teamwork.

Introduction

Human error is responsible for over 70% of aircraft accidents (Helmreich & Foushee, 1993). The primary source of human performance error is failure in team communication and in team coordination (Helmreich & Foushee, 1993). In response to these findings, the aviation community expanded training programs, which had traditionally focused on technical aspects of flight and were targeted toward individual pilots, to include psychological training for all members of flightcrews. These training programs, once known as Cockpit Resource Management, are now known as Crew Resource Management (CRM).

Lauber (1984) defined CRM as “using all available resources—information, equipment, and people—to achieve safe and efficient flight operations.” CRM focuses on psychological training in group dynamics, leadership, interpersonal communications, and decision-making (Helmreich & Merritt, 1998). The goal of CRM is to train flightcrews to operate as a cohesive team.

Research on the effectiveness of CRM demonstrates that training has a positive impact (Helmreich, 1991). CRM programs produce favorable participant reactions (e.g., Alliger, Tannenbaum, Bennett, & Traver, 1997; Salas, Burke, Bowers, & Wilson, 2001), learning, (e.g.,

Hayward & Alston, 1991; Salas et al., 2001; Salas, Fowlkes, Stout, Milanovich, & Prince, 1999), and

application of learned behavior (e.g., Leedom & Simon, 1995; Salas et al., 2001). Finally, Helmreich, Wilhelm, Gregorich, and Chidester (1990) report that CRM training increases the percentage of crews with above average ratings in performance and decreases the percentage of crews with below average ratings.

The growing success of CRM training in the United States prompted other nations to adopt this program. However, some components of training were more readily understood and accepted in some countries than in others. For example, Korean pilots did not understand a CRM guideline to be assertive in the cockpit (Helmreich & Merritt, 1998). American developers of CRM failed to consider the cultural needs of other nations when exporting this training program.

There has been a widespread belief in the aviation community that the cockpit is a culture-free zone (Helmreich & Merritt, 1998; Helmreich, Wilhelm, Klinec, & Merritt, 2001). Given the difficulty in transferring CRM training to other cultures, the model of CRM developed and demonstrated to be effective in the United States may not generalize successfully to other, especially nonwestern, cultures (Davis & Kuang, 2000). CRM appears to be contextually constrained by culture.

Data suggest that there are substantial differences in the way that flightcrews perform as a function of national culture and that these areas of difference have implications for safety (Helmreich & Merritt, 1998; Johnston, 1993; Merritt, 1996; Merritt & Helmreich, 1996a; Merritt & Helmreich, 1996b; Sherman, Helmreich, & Merritt, 1997). Airline accident rates vary across nations. Developing countries in Africa, Latin America, and Asia have accident rates eight times those of industrialized nations in Europe, North America, and the Middle East (Weener, 1990). Phelan (1994) acknowledges that disparities in economic development and infrastructure may explain some of these differences in accident rates, but contends that cultural differences account for additional variability.

Culture differences related to teamwork may explain, in part, failure in generalizability of CRM training to other countries. The impact of national culture on flightcrew performance is examined within the context of a team performance model. A team is defined as “a distinguishable set of two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have each been assigned specific roles or functions to perform, and who have a limited life-span of membership” (Salas, Dickinson, Converse, & Tannenbaum, 1992). Given their composition, tasks, and context, flightcrews satisfy the definition of a team. Teamwork is defined as behaviors of team members that contribute to sharing of information and coordination of activities (Dickinson & McIntyre, 1997). Teamwork among flightcrew members is critical for effective performance and safety.

CRM may be conceptualized as a three-factor model of team behavior consisting of inputs, throughput, and outputs. Inputs refer to member, team, and organizational characteristics. Throughput transforms inputs into outputs. Crew teamwork constitutes throughput in this model. Finally, outputs are results of team activity. In this context, flightcrew performance and flightcrew error are the outputs.

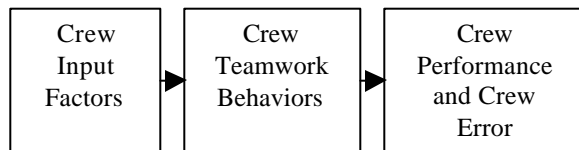


Figure 1. Model of Flightcrew Performance (Adopted from Davis & Kuang, 2000)

The focus of the present study is on two input factors, national culture and cultural values.

Throughput is confined to three teamwork behaviors, shared mental model, situational awareness, and workload perceptions.

Influence of National Culture on Teamwork

National culture influences many components of teamwork (Granrose & Oskamp, 1997), including communication (Orasanu, Fischer & Davison, 1997), decision-making (Ilgen, LePine, & Hollenbeck, 1997), influence processes (House, Wright, & Aditya, 1997), and role relationships (Earley & Gibson, 2002).

Teamwork mediates the relationship between culture and the likelihood of aviation accidents (Davis & Kuang, 2000). Culture and teamwork may also influence other mediating characteristics, such as error management, that then affect the likelihood of aircraft accidents (Helmreich et al., 2001).

Most cross-cultural research relevant to flightcrew performance and teamwork behaviors addresses cultural values (Davis & Kuang, 2000). Cultural values represent desired traits and behaviors shared by members of cultural groups (Davis & Kuang, 2000), which predispose individuals to favor certain end states or outcomes (Kluckhohn & Strodtbeck, 1961). The most commonly studied cultural values are individualism-collectivism (focus on self versus focus on harmony with one’s work group or family), power distance (acceptance of unequal power or authority relationships), and uncertainty avoidance (extent to which ambiguity is avoided).

Collectivism, power distance and uncertainty avoidance have been shown to influence cockpit communication and decision-making (Redding & Ogilvie, 1984). These values are also related to pilots’ attitudes concerning CRM characteristics, such as independence, command, preferences for automation, and rules—attitudes that may influence flightcrew performance and the probability of aviation accidents (Helmreich, Foushee, Benson, & Russini, 1986; Helmreich & Merritt, 1998).

Cultural values also affect attitudes toward flightcrew performance (Merritt & Helmreich, 1996a). For example, crews from Asian nations tend to emphasize group solidarity and harmony (collectivism) and differences in authority (high power distance). Crews from the US emphasize individualism and egalitarianism (low power distance) (Davis & Kuang, 2000). Cultural differences influence cognitive processes, such as how individuals perceive, encode, store, and process information (Matsumoto, 2000), as well as cognitive style, such as field dependence

(Triandis, 1997). Finally, culture affects nature and frequency of teamwork behaviors, such as communication and feedback as well as frequency of errors (Davis & Kuang, 2000).

Culture influences teamwork behaviors in the cockpit, yet little is known about the impact of culture on teamwork processes such as situational awareness, shared mental model, and workload perceptions. This study seeks to address this gap in the literature by examining the influence of culture on these three teamwork components.

Situational Awareness

Situational awareness involves the ability to maintain an accurate perception of one's internal and external environment (Swezey, Llaneras, Prince, & Salas, 1991). All pilots must practice situational awareness to ensure effectiveness and safety (Prince & Salas, 1993). However, team situational awareness is just as important for team performance and safety. Team situational awareness is not simply a sum of individual situational awareness. Rather, it represents the shared understanding among team members at one point in time. This awareness is facilitated by team processes or behaviors that allow shared assessments to be developed and maintained (Salas, Prince, Baker, & Shrestha, 1995). Team situational awareness, then, is dependent upon teamwork behaviors in the cockpit.

Situational awareness has been identified as the single most important factor in aviation mission performance (Endsley, 1988). In an analysis of Navy and Marine aircraft accidents, Hartel, Smith, and Prince (1991) found that lack of situational awareness was cited most frequently as a causal factor. Similarly, Leedom (1990) found that failure to provide situational information to crewmembers was a causal factor in Army aircraft accidents. Finally, Orasanu (1990) found that more effective flightcrews had captains and first officers that exhibit higher situational awareness compared to less effective flightcrews.

Shared Mental Models

Shared mental models consist of attitudes, expectations, knowledge, and behaviors that team members share (Cannon-Bowers & Salas, 1990). These mental models help flightcrews describe, explain, and predict events in their environment (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). In order to operate effectively and adaptively to changing environmental conditions, flightcrew members must use their own knowledge as a basis for selecting actions that are consistent and coordinated with those of other crew members (Mathieu et al., 2000). Shared mental

models have been shown to predict quality of team processes and team performance (Mathieu et al., 2000).

Workload

Workload refers to information processing demands that are placed on an individual or team by a task (Davis & Kuang, 2000). Team workload influences team performance. Under conditions of high or low workload, performance declines (Bowers, Braun, & Morgan, 1997; Johnston & Briggs, 1968). Effective flightcrews are able to adjust their teamwork skills to meet increased workload demands, while less effective flightcrews are not (Davis & Kuang, 2000).

Relationships Among Situational Awareness, Shared Mental Models, and Workload

Situational awareness, shared mental model, and workload perceptions are interrelated teamwork behaviors. Situational awareness is, in part, dependent on shared mental models based on knowledge, expectations, or past experiences (Mogford, 1997; Sarter & Woods, 1991). Situational awareness is also related to perceptions of workload. Under conditions of high or low workload, situational awareness suffers due to excessive cognitive demands or vigilance problems, respectively (Endsley, 2000).

Shared mental models are also related to workload. In a situation of excessive workload, teams are not able to actively engage in verbal strategizing to adapt to a dynamic situation. Shared mental models become crucial to team functioning because they allow members to predict the information and resource requirements of their teammates. Members can then act on their understandings of the situation in order to adapt quickly and successfully (Mathieu et al., 2000).

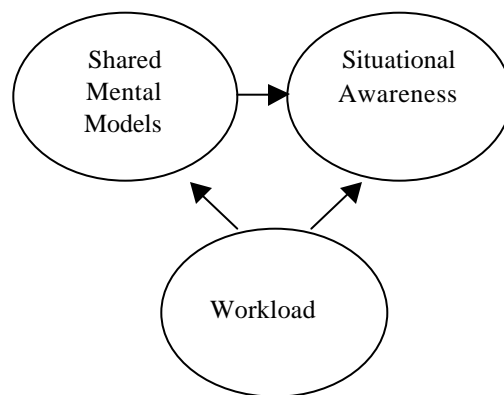


Figure 2. Relationships Among Situational Awareness, Shared Mental Models, and Workload

Method

Participants

One hundred ninety-six Chinese and American graduate and undergraduate students participated in this study. Only males were used because too few female Chinese students were available. Average age for all participants was 26.39 years. Mean age for American participants was 24.94 years and mean age for Chinese participants was 27.87 years.

Design and Procedure

Subjects were paired in a same culture condition and a mixed culture condition for a total of one hundred forty-nine two-person teams. There were three experimental conditions in total—single culture American teams (N = 49), single culture Chinese teams (N = 47), and mixed culture Chinese-American teams (N = 53). All participants completed a single culture condition. Half of the participants also completed a mixed culture condition. Scenario type and role (i.e., pilot or copilot) were counterbalanced across experimental sessions. Our independent variables are culture, represented by the three experimental conditions described above, and cultural values, measured by the Liang (1999) Individualism-Collectivism and Power Distance Scales and Schwartz Cultural Values Survey (SVS; Schwartz & Bilsky, 1987; Schwartz & Bilsky, 1990). Our dependent variables are three team behaviors, situational awareness, shared mental model, and workload perceptions.

Participants were trained to fly a Cessna 182S using Microsoft Flight Simulator 2000 Professional Edition. Training focused on take-off, landing, simple navigation using GPS, use of a flight computer to calculate fuel levels, ATC communications, and pilot/copilot roles and responsibilities. Participants typically completed training within eight hours. Participants who successfully passed the Microsoft Flight Simulator 2000 proficiency check ride moved to the experimental phase of the study.

Each pair of subjects flew two scenarios created for this study. Each scenario contained anomalies that required participants to demonstrate team behaviors. The first scenario contained adverse weather conditions; the second scenario presented low fuel and conflicting directions. Subjects were randomly assigned the role of pilot in one scenario and the role of copilot in the other scenario. Each scenario lasted approximately 45 minutes. Teams were videotaped while flying these scenarios. After the team completed

its scenario, team members individually completed measures of situational awareness, shared mental model and workload.

Measures

Cultural Values. Individualism-collectivism (IC) was measured using a scale developed by Liang (1999). His research was based on the work of Chen, Meindl, and Hunt (1997), Triandis (1995), and Wagner (1996). People with strong individualist values are typically self-oriented. They perceive themselves as individual actors and place their personal interests above those of the collective society. By contrast, members of strongly collectivist societies are socially oriented. They place the interests and well being of their groups ahead of individual interests. Collectivist societies also place great value on interpersonal relationships, group welfare, and equality. Liang (1999) validated the IC scale on a Chinese sample. The IC scale contains seven items. Participants responded to each item on a scale of one (strongly disagree) to five (strongly agree). High scores indicate a focus on collectivism.

Power distance (PD) was assessed using a scale developed by Liang (1999) and based on work by Earley and Erez (1997). Power distance is the degree to which less powerful members of a given society expect and accept that power is distributed unequally (Hofstede & Bond, 1984). There are ten items in this scale. Participants responded to each item on a scale of one (strongly disagree) to five (strongly agree). High scores indicate high power distance.

The Schwartz Cultural Values Survey (SVS) measures cultural values, such as equality in the workplace, social power, sense of belonging, detachment, respect for tradition, and acceptance (Schwartz & Bilsky, 1987, Schwartz & Bilsky, 1990). We used the SVS to measure the following values: conformity, benevolence, tradition, universalism, self-direction, stimulation, hedonism, achievement, power, and security (see Table 1). The SVS contains fifty-six value items that are divided into two lists. Subjects rated the values on the two value lists according to a nine-point scale ranging from negative one (opposed to personal values) to seven (of supreme importance). Higher scores indicate that individuals believe the construct to be of high personal importance or value.

Table 1. Schwartz Cultural Values Survey Factors

Factor	Description
<i>Achievement</i>	Measures personal success according to social standards.
<i>Benevolence</i>	Measures preservation and enhancement of the welfare of people to whom one is close.
<i>Conformity</i>	Measures restraint of actions and impulses that may harm others and violate social expectations.
<i>Hedonism</i>	Measures pleasure or sensuous gratification.
<i>Power</i>	Measures social status or dominance over people and resources.
<i>Security</i>	Measures safety and stability of society, relationships, and self.
<i>Self-Direction</i>	Measures independence of thought and action.
<i>Stimulation</i>	Measures excitement and novelty.
<i>Tradition</i>	Measures respect and commitment to cultural or religious customs and ideas.
<i>Universalism</i>	Measures understanding, tolerance, and protection for the welfare of all people and nature.

Team Behaviors. Videotapes were reviewed for the presence of situational awareness using dimensions developed by Muniz, Stout, Bowers, and Salas (1997). Subject matter experts viewed videotapes of each team and recorded instances of situational awareness. The total number of situational awareness episodes for each team was calculated and recorded. Two trained observers independently scored six tapes to determine inter-rater reliability for this team behavior. Average inter-rater reliability for situational awareness across the six videotapes was 0.83.

Shared mental model of task work was assessed using a questionnaire developed for this study, similar to one developed by Mathieu et al. (2000). Participants were given pairs of concepts critical to flying and were asked to rate their strength of relationship on a 9-point agreement type scale. This scale ranged from -4 (negatively related) to +4 (positively related). A rating

of 0 meant that the concepts were not related at all. Ten attributes of the task were selected based on their relevance to flight: altimeter, speed, stalling, climbing, landing, flare, throttle, straight and level flight, and pitch. Participants completed a total of 45 judgments.

Workload perceptions were measured with the NASA Task Load Index (TLX), a subjective workload measure developed by Hart and Staveland (1988). The TLX consists of the following six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration. For each dimension, respondents indicate their perceptions on a one hundred-point, bipolar scale. TLX dimensions are labeled from either *low to high* or *good to poor*.

Results

The unit of analysis was the team. Therefore, we aggregated all values and team behaviors to the team level using the mean of pilot and copilot scores for these items.

We conducted a series of univariate analyses of variance (ANOVAs) to examine differences in team behaviors as a function of experimental condition. Results indicate significant differences in situational awareness across the three conditions, $F(2, 146) = 9.75, p = .000$, exceeding the Bonferroni adjusted level of significance. According to Scheffe post hoc tests, single culture American teams ($M = 8.01$) displayed significantly more situational awareness than single culture Chinese teams ($M = 4.10$), $p = .000$. No differences in shared mental model were found for team type, $F(2, 143) = .99, p = .375$. Finally, there were significant differences in physical workload perceptions across the three experimental conditions, $F(2, 146) = 10.29, p = .000$. Scheffe post hoc tests reveal significant differences in physical workload between single culture American teams ($M = 33.57$) and single culture Chinese teams ($M = 50.69$), $p = .000$. There were also significant differences in physical workload between single culture Chinese teams ($M = 50.69$) and mixed culture teams ($M = 40.47$), $p = .025$.

Next, we examined the influence of cultural values on teamwork behaviors using hierarchical multiple regression. We entered experimental condition in step one. This analysis depicts the influence of culture on each team behavior. In step two, we entered cultural values (IC/PD and SVS). This analysis depicts the influence of cultural values on teamwork behaviors after controlling for experimental condition. The adjusted Bonferroni significance level for all analyses was .033.

Situational Awareness

In the IC/PD analysis, experimental condition entered in step one predicted situational awareness ($R^2 = .12, p = .000$). Single culture American teams demonstrated more situational awareness than single culture Chinese teams ($\beta = .34, p = .000$). In step two, IC and PD did not explain significant unique variance in situational awareness (? $R^2 = .03, p = .062$). The final equation was significant, $F(4, 144) = 6.41, p = .000$.

In the SVS analysis, experimental condition entered in step one predicted situational awareness ($R^2 = .12, p = .000$). Single culture American teams demonstrated more situational awareness than single culture Chinese teams ($\beta = .34, p = .000$). In step two, Schwartz values failed to explain significant unique variance in situational awareness (? $R^2 = .05, p = .682$). The final equation was significant, $F(12, 136) = 2.22, p = .014$.

Shared Mental Model

In the IC/PD analysis, neither experimental condition ($R^2 = .01, p = .375$) nor IC/PD (? $R^2 = .02, p = .170$) explained significant variance in shared mental model. The final equation was not significant, $F(4, 141) = 1.40, p = .238$.

In the SVS analysis, neither experimental condition ($R^2 = .01, p = .375$) nor Schwartz values (? $R^2 = .10, p = .134$) explained significant variance in shared mental model. The final equation was not significant, $F(12, 133) = 1.45, p = .151$.

Workload

Mental Workload. In the IC/PD analysis, neither experimental condition ($R^2 = .02, p = .261$) nor IC/PD (? $R^2 = .01, p = .679$) explained significant variance in mental workload. The final equation was not significant, $F(4, 144) = .87, p = .486$.

In the SVS analysis, neither experimental condition ($R^2 = .02, p = .261$) nor Schwartz values (? $R^2 = .07, p = .480$) explained significant variance in mental workload. The final equation was not significant, $F(12, 136) = 1.03, p = .428$.

Physical Workload. In step one of the IC/PD analysis, experimental condition predicted physical workload perceptions ($R^2 = .12, p = .000$). Single culture Chinese teams reported greater physical workload than single culture American teams ($\beta = -.35, p = .000$). In step two, IC and PD did not explain

significant unique variance in physical workload (? $R^2 = .01, p = .397$). The final equation was significant, $F(4, 144) = 5.60, p = .000$.

In the SVS analysis, experimental condition entered in step one predicted physical workload perceptions ($R^2 = .12, p = .000$). Single culture Chinese teams reported greater physical workload than single culture American teams ($\beta = -.35, p = .000$). In step two, Schwartz values did not explain significant additional variance in physical workload (? $R^2 = .07, p = .357$). The final equation was significant, $F(12, 136) = 2.66, p = .003$.

Temporal Workload. In the IC/PD analysis, neither experimental condition ($R^2 = .03, p = .142$) nor IC and PD (? $R^2 = .01, p = .426$) predicted temporal workload perceptions. The final equation was not significant, $F(4, 144) = 1.42, p = .232$.

In the SVS analysis, neither experimental condition ($R^2 = .03, p = .142$) nor Schwartz values (? $R^2 = .10, p = .135$) predicted temporal workload perceptions. The final equation was not significant, $F(12, 136) = 1.62, p = .094$.

Performance. In the IC/PD analysis, neither experimental condition ($R^2 = .04, p = .057$) nor IC and PD (? $R^2 = .01, p = .346$) explained significant variance in performance perceptions. The final equation was not significant, $F(4, 144) = 2.00, p = .098$.

In step one of the SVS analysis, experimental condition did not explain significant variance in performance perceptions ($R^2 = .04, p = .057$). In step two, Schwartz values predicted performance ratings (? $R^2 = .14, p = .013$). Teams higher in conformity ($\beta = .24, p = .024$) and self-direction ($\beta = .25, p = .015$) values had better perceptions of performance.

Effort. In the IC/PD analysis, neither experimental condition ($R^2 = .02, p = .218$) nor IC and PD (? $R^2 = .00, p = .730$) predicted perceived effort. The final equation was not significant, $F(4, 144) = .92, p = .454$.

In the SVS analysis, neither experimental condition ($R^2 = .02, p = .218$) nor Schwartz values (? $R^2 = .05, p = .735$) predicted perceived effort. The final equation was not significant, $F(12, 136) = .82, p = .626$.

Frustration. In the IC/PD analysis, neither experimental condition ($R^2 = .02, p = .228$) nor IC and PD (? $R^2 = .01, p = .359$) explained significant variance in frustration ratings. The final equation was not significant, $F(4, 144) = 1.26, p = .287$.

In the SVS analysis, neither experimental condition ($R^2 = .02, p = .228$) nor Schwartz values ($R^2 = .06, p = .559$) explained significant variance in frustration ratings. The final equation was not significant, $F(12, 136) = .98, p = .476$.

Discussion

We found significant differences across the three experimental conditions (i.e., team types) with respect to situational awareness and physical workload perceptions. However, we did not find meaningful differences across the three team types for shared mental model and remaining workload perceptions.

Our hypothesis that differences in cultural values impact team behaviors was largely unsupported in this study. One notable exception was in the Schwartz values analysis with perceived performance as the criterion. We found that teams higher in conformity (i.e., teams that conform to social expectations) and self-direction (i.e., teams that value independent thought and action) values evaluated their performance more favorably.

It is possible that the cultural values measures used in this study, IC, PD, and SVS, did not adequately capture the cultural values relevant to team behaviors studied here. Another limitation to our study may be the level at which we analyzed data. The unit of analysis for this study was the team. We aggregated measures of cultural values and team behaviors using the mean of pilot and copilot scores. Perhaps this approach made it more difficult to detect the influence of cultural values on team behaviors. Mean values tend to mask variability observed in individual scores.

We contend that culture is important in the performance of cockpit crews and in CRM training. Much research is still needed to identify the level at which culture should be studied and how it exerts its influence on teams.

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