8 Social Cybernetics of Team Performance Variability

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8.1 INTRODUCTION

The complex nature of social behaviors poses significant challenges to researchers and practitioners alike interested in understanding and managing sources of team performance variability. Teamwork is generally defined as a group of individuals working together to accomplish a common goal or purpose. Paradoxically, while most human factors researchers are comfortable attributing goal-directed behavior to teams, there is a general reluctance to delve into the scientific basis of these controlled behaviors. The inconsistent way that controlled behaviors are conceptualized at the team level versus individual team-member level also reveals the need for a more coherent systems approach. A working premise of this chapter is that a more consistent application of behavioral systems principles in modeling team behaviors can address these shortcomings and go a long way toward improving our understanding of sources of team performance variability.

Social cybernetics, an area of emphasis within behavioral cybernetics (T.J. Smith & Smith, 1987a), provides a comprehensive systems approach for identifying the key control processes and task design factors that contribute to team performance variability. As summarized below, empirical research studies have identified fundamental ways that individual team members engage in joint control activities during teamwork, and how these design factors impact team performance variability (this evidence shows that context specificity influences variability in team performance, recapitulating the theme of performance-design interaction (Chapter 1, Section 1.1.2) addressed in previous chapters). The social cybernetic model also provides a means to conceptualize the inherent trade-off between behavior that is controlled by individual team members or jointly controlled by the team. A key to understanding this trade-off is to understand the origins of behavioral control from a multilevel perspective. Systematic examination of these multilevel control relationships through the lens of social cybernetics can help guide human factors design efforts to limit team performance variability.

The primary author of this chapter has a longstanding familiarity with the social cybernetic model, having been involved in basic research and field applications in the 1970s under the direction of Professor K.U. Smith at the University of Wisconsin-Madison, and subsequently having applied the social cybernetic model in field studies of occupational health and safety and also in laboratory studies of the social psychophysiology of teamwork. The following themes and topics are covered in this chapter as a way to introduce the social cybernetic model and demonstrate its utility in the study of team performance variability: Section 8.2 is titled the Cybernetic Fundamentals of Feedback and Feedforward Control; Section 8.3 is the Longstanding Scientific Reservations about Cybernetic Psychology; Section 8.4 is the Social Cybernetics and Teamwork; Section 8.5 is titled the Social Cybernetic Studies of Social Interaction and Teamwork Through 1994; Section 8.6 is the Social Cybernetics Research since 1994; Section 8.7 is the Design Imperatives for Homeokinesis at the Team Level; and Section 8.8 is titled the Assessment of Homeokinesis at the Team Level.

8.2 CYBERNETIC FUNDAMENTALS OF FEEDBACK AND FEEDFORWARD CONTROL

Principles of behavioral cybernetics have already been introduced in Chapter 1 (Section 1.3.3), and so only those principles critical to understanding the social cybernetics of teamwork are covered here. To begin with, behavioral cybernetics is grounded in principles of control theory, including feedback control (compensatory control in response to error) and feedforward control (anticipatory or projective behaviors taken in advance to prevent error). Empirical evidence indicates that the control (or regulation) of social behaviors normally depends on a combination of both feedback and feedforward control (T.J. Smith & Smith, 1987a).

Feedback control (or error control) is relevant even in simple social behaviors. For example, when two people reach out to shake hands with each other, feedback control of hand position occurs in relation to the instantaneous distance between their hands. Poor quality feedback, such as not being able to see this instantaneous distance clearly, is referred to as noncompliant feedback because it can perturb or impair the ability to control the behavior involved. Feedback can be noncompliant due to spatial displacements (e.g., rotation, inversion) or temporal displacements (e.g., time delays), both of which have been found to significantly impair performance and increase performance variability (detailed in Chapter 5). Other transformations of feedback that can perturb behavior include discontinuity and lack of coherence with other sources of feedback.

Feedforward control (or projective control) of behavior is analogous to skilled steering behavior, where control actions are taken in advance of error actually occurring. Anticipating a slip or fall by reaching out to provide physical support to a person prior to them falling is an example of feedforward control in social behavior. Feedforward control is based, in part, on the participant's memories of past events and experiences. Even simple examples of feedforward control in social behaviors normally also involve some dynamic closed-loop feedback control of error. This enables timely (i.e., just-in-time) corrective adjustments to social behaviors that are largely guided by feedforward control.

8.3 LONGSTANDING SCIENTIFIC RESERVATIONS ABOUT CYBERNETIC PSYCHOLOGY

Since the scientific revolution, behavioral scientists have not been all that receptive to the idea that individual behavior can be both self-regulated and purposeful. According to Greenwood (2009), the originator of the cybernetic model for human-machine systems, Norbert Wiener, worked hard to convince skeptics that the concept of self-regulation had scientific standing. Wiener pointed out that it was possible to build a machine that self-regulated its behavior through use of feedback control, showing that self-regulated behavior in no way relies on immaterial or supernatural causes (Rosenblueth et al., 1943). The continued reluctance on the part of the behavioral science community to embrace the concept of self-regulated purposeful human behavior can be attributed, in part, to the great success of the physical scientist Sir Isaac Newton. His universal law of gravity made no reference to purposeful behavior, and this set the standard for what was considered a good scientific model (Greenwood, 2009). Even so, purposeful behavior was central to many of the behavioral models of early notable psychologists; William James promoted concepts of self-improvement and the importance of taking charge of your own life, John Dewey's functionalism demanded that motor-sensory control always be considered in the context of purposeful behavior, and Edward Tolman's neobehaviorism emphasized purposeful molar behaviors over low-level environmentally driven behaviors.

Nonetheless, simplified stimulus-response animal models that assumed environmental determinism still dominated much in the field of psychology and discouraged scientific consideration of the basis of cybernetic self-regulation. Even present-day cognitive models of behavior typically lack specific mechanisms to explain how behavior is organized and controlled, focusing instead on various ways that information can be processed. For example, Bandura's work on the social cognitive theory of self-regulation (1991) provides no adequate physiological mechanism to explain self-regulation. Furthermore, most social psychologists elected to use a reductionist approach when modeling group behavior by assuming that individuals react to social stimuli in the same ways that individuals react to other complex environmental stimuli. However, such explanations deny the possibility for emergent behaviors in social systems, a position that is contrary to modern systems science (see Chapter 2, Section 2.4, for a discussion of emergent behavior in self-organized systems).

One shortcoming in Wiener's original cybernetic model that may have contributed to behavioral researchers choosing reductionism over principles of self-regulation was the lack of a mechanism to explain how self-regulation in closed-loop systems could be sustained by living organisms. This shortcoming has been addressed in the more comprehensive behavioral cybernetics model (T.J. Smith & Smith, 1987a) where the primary mechanism that makes self-regulation possible is the reciprocal impact of motor (muscle) activity on both sensory stimulation and internal physiological states. Claiming that behavior can be used to regulate behavior may at first seem circular; however, the many reciprocal effects that motor activity has on current and subsequent behavior does provide a viable means for the self-regulation of ongoing behavior. For example, motor behavior that one uses to manipulate an object in the environment immediately produces self-generated sensory feedback through dynamic changes to the environment as well as from internal kinesthetic and other sensory systems linked to muscle and limb positioning. Also important to this control process, motor activity depends on metabolism, and this results in motor activity dictating the majority of energy use in the body during active behaviors. Many physiological systems also automatically respond to any change in metabolic activity, including cardiorespiratory functions, energy storage or outlay by the liver, and even neural-hormonal systems in which hormones are released to have multifold effects throughout the body (K.U. Smith, 1973).

The widespread reciprocal effects of motor behavior on internal physiological state enable what is referred to in behavioral cybernetics as bioenergetic control, which impacts both ongoing and subsequent behaviors, including central nervous system functioning that is already affected by self-generated sensory feedback. This highlights the importance of ongoing dynamic motor activity for the effective self-regulation of behavior—representing the concept of homeokinesis first introduced by K.U. Smith and Smith (1966). Homeokinesis can be contrasted with homeostasis, which is largely associated with passive and steady-state forms of physiological functioning during periods of rest and inactivity.

One final scientific concern that helps explain why behavioral researchers remain hesitant to adopt cybernetic models of behavior is that the origination of self-regulated behavior in organic systems is not readily apparent nor easily determined. For example, any compensatory control based on error feedback must first have a reference target or set point for error. There is no simple answer for where these set points come from in the behavioral cybernetics model. As explained above, self-regulation of behavior not only involves feedback control based on error, it also involves feed-forward control that consists of control actions that occur prior to error occurring. Thus, projective bioenergetic control and projective control of self-generated sensory feedback are necessary to establish and sustain self-regulation of behavior.

In behavioral cybernetic theory, this suggests that the level of control can progressively increase over time in a nonlinear fashion once behavior is underway; for example, as reflected in the process of waking up and getting underway every morning. Those seeking a causal chain of events to explain these closed-loop behaviors may never be fully satisfied with this explanation, but conducting research on how purposeful team behavior is controlled and what environmental and task designs best support this control should not be avoided for this reason. Moreover, research scientists in other fields have not become scientifically immobilized over similar unanswered questions relating to causality; for example, the lack of knowledge of events prior to the Big Bang has not prevented physicists from conducting research on physical dynamics that are occurring after this event. As summarized below, there is ample scientific evidence that the human factors design of task environments affects social cybernetic control relationships as well as performance, and the social cybernetic model can be used to help understand and manage sources of team performance variability by systematically examining how behavior is controlled.

8.4 SOCIAL CYBERNETICS AND TEAMWORK

A basic form of social tracking occurs when one person actively attends to (or follows or tracks) the activity of another person. Even the simplest social tracking behaviors require some degree of skilled behavior on the part of the observer. In the case of visual social tracking for example, there is usually a need for both feedback and feedforward control of head and eye position in order to continuously track the activities of another person. Feedforward control in this case could involve anticipating which activity another person might initiate next and watching for the earliest signs of that activity. Feedback control in this case could involve compensatory control of eye movements when reacting to some unexpected activities of the other person. When two people are tracking each other simultaneously, the cybernetic aspects of the social behavior become much more complex and interesting. Any motor-sensory activity by one person serves as a new source of sensory feedback for the other person, which can then serve as the basis for further motor-sensory tracking behavior on the part of the first person, and so on, as depicted in Figure 8.1. In behavioral cybernetics, this linking up of behavior through joint motor-sensory control activity is variously referred to as joint motor-sensory control, integrated motor-sensory control, yoked motor-sensory control, or simply mutual control or mutual social tracking.

Depending on the nature of the social interaction, social tracking may demand an increased degree of effort and social skill. For example, when two individuals are in the process of completing an interdependent task, each individual is not only engaged in controlling aspects of his or her own behavior based on sources of self-generated feedback; each individual must also control some aspects of his or her behavior in relation to the new sources of sensory feedback that are generated while interacting with the other person. Multiple team members trying together to accomplish a shared goal or purpose further adds to the complexity of these motor-sensory control

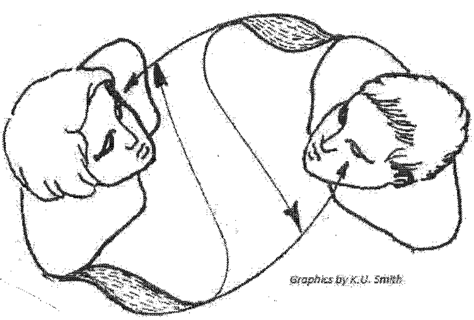

FIGURE 8.1 Mutual social tracking.

relationships, impacting the bioenergetic control of individual team members and their ability to regulate their own behaviors effectively within the team context.

8.4.1 Modes of Social Tracking

Three distinct modes of social tracking involving closed-loop motor-sensory feedback control and/or feedforward control have been identified and verified through empirical testing (T.J. Smith & Smith, 1987a): (1) imitative social tracking, (2) parallel-linked social tracking, and (3) serial-linked (or series-linked) social tracking. In combination or in isolation, these three modes of social tracking can be used to characterize all forms of teamwork, providing a basis to consider how homeokinesis at the team level can be achieved and maintained via the feedback and feedforward control behaviors of team members.

8.4.1.1 Imitative Social Tracking

This mode of social tracking occurs when one team member imitates the behavior of another team member, as depicted in Figure 8.2. As shown, to be successful the person imitating his or her teammate's behaviors (the imitator) must actively work to minimize the error between his or her own behavior and that of the teammate. In training situations, a trainer would normally also track the behavior of the imitator in a closed-loop manner and adjust his or her behavior using feedback and feedforward control so that the imitator is able to keep pace and duplicate the target behavior without serious error. Furthermore, team leaders may often serve as a model or target of imitative social tracking. More effective team leaders would provide verbal and other sources of feedback to individual team members to reduce error and variability during imitative tracking. For example, human factors design can further support feedback and feedforward control during imitative tracking by assuring that adequate sources of compliant feedback are always available.

8.4.1.2 Parallel-Linked Social Tracking

The parallel mode of social tracking occurs when all team members can exert direct control over a system they are responsible for controlling and also receive sensory feedback about how the system is responding to their control inputs. This process is

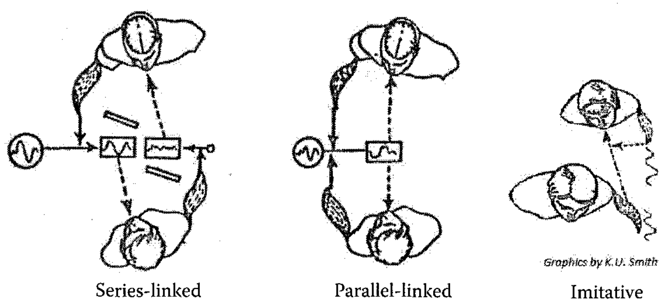

FIGURE 8.2 The three modes of social tracking.

also depicted in Figure 8.2, in which two team members are responsible for maintaining the status quo of a system. Disturbances to the system are depicted as a random waveform on the left side of the diagram, which each team member is able to help compensate for via control actions. An advantage of parallel social tracking is that control redundancy across team members can sometimes increase system reliability. However, a disadvantage is that a team member can have difficulty discerning whether a change in system status is due to his or her control inputs or the control inputs of other team members. This uncertainty in parallel-linked control may result in team members working at cross purposes, with control actions canceling out or adding together in undesirable ways. The resulting confusion can contribute to role ambiguity and teams failing to adequately respond to system disturbances. Human factors design can support this mode of social tracking and significantly reduce performance variability by making it possible for team members to track the control actions of other participants in addition to system responses.

8.4.1.3 Serial-Linked (or Series-Linked) Social Tracking

The serial-linked mode of social tracking occurs when the control actions and/or the feedback information necessary to achieve closed-loop control is somehow transferred through team members in a chainlike manner. In the case of series-linked tracking by a two-person team, only one team member can exert direct control over the system under their control, and only the second team member can receive sensory feedback about system responses to control inputs and determine what control actions are needed. As depicted in Figure 8.2, the random disturbance to the system depicted at the left must be compensated for by the control actions of the team. Many military command–control relationships as well as supervisor–subordinate teamwork relationships in the workplace are examples of series-linked social tracking. Advantages to series-linked tracking include role specificity and clear divisions of labor. Disadvantages include the risk of delayed actions and responses propagating across the chain of participating team members that can amount to substantial temporal displacements in feedback control, contributing to performance variability due to control instability. Apart from delayed actions or delayed feedback, errors can also propagate down the serial chain of participants and not be immediately detected.

8.4.2 Feedback Perturbation of Social Tracking

All modes of social tracking are susceptible to ergonomic design factors that impact performance variability by affecting the quality of feedback control relationships discussed earlier. Imitative social tracking performance can be perturbed and/or degraded by low-quality sensory information or by some form of noncompliant feedback described earlier because these compromise the imitator's ability to accurately and reliably match behaviors. For example, poor lighting would make it difficult for the imitator to clearly see the actions of the social target or to accurately detect any error differential between their own behavior and that of the social target. In the case of parallel social tracking, the lack of a communication pathway to provide information about the control actions being taken by other team members could result in team members duplicating control inputs and working at cross purposes.

Serial-linked tracking is dependent on a series of yoked control behaviors that can be seriously perturbed or degraded by time delays, such as a team member being slow to respond to a request for immediate action.

8.5 SOCIAL CYBERNETIC STUDIES OF SOCIAL INTERACTION AND TEAMWORK THROUGH 1994

Findings from earlier social tracking research are reviewed in detail elsewhere (T.J. Smith & Smith, 1987a, 1988b). Cybernetic research on sources of social performance variability related to teamwork was initially reviewed and summarized by T.J. Smith et al. (1994a), as detailed below.

8.5.1 Design Factors and Variability in Social Tracking

The preponderance of variability and specialization in social tracking performance is attributable not to a learning effect but rather to the effect of the human factors design of the tracking task and interface (Beare et al., 1985; Ting et al., 1972). Design factors of significance that may be specified include sensory feedback control parameters and conditions, mix of tracking modalities employed, temporal and spatial properties of sensory feedback, and the level and pattern of interpersonal, group, institutional, and/or human-system social relationships.

8.5.2 Sensory Feedback Modality and Social Tracking Skill

Relative to visual-manual social tracking, accuracy and proficiency are greater for tactile, kinesthetic, and auditory social tracking (Cherry & Sayers, 1956; Rothe, 1973). Social tracking based on nonverbal sensory feedback often is more effective than verbal tracking in promoting social learning and communication (K.U. Smith & Smith, 1973). For all sensory modalities, the accuracy of interactive social tracking is comparable to that of individual tracking except under feedback delay conditions when the latter is superior to the former at all delay levels. Mutual social interaction entailing reciprocal exchange of sensory feedback (i.e., series- or parallel-linked tracking) is more effective than purely imitative tracking.

8.5.3 Learning of Social Tracking Skills

Even with provision of real-time feedback of tracking performance, social learning of specific social tracking tasks is highly variable, relatively limited and inconsistent, and unstable (Kao & Smith, 1971; Sauter & Smith, 1971).

8.5.4 Physiological Feedback Effects in Social Tracking

Movement compliance during interactive social tracking entails a concomitant synchronization of physiological functioning of the social partners (M.J. Smith, 1973; T.J. Smith & Smith, 1987a). Computerized social research has provided concrete evidence for such interactive physiological tracking for both cardiac (M.J. Smith, 1973) and ventilatory (Sauter, 1971) activity.

8.5.5 Effects of Sensory Feedback Perturbations on Social Tracking

Real-time temporal delays or spatial displacements in sensory feedback severely degrade the accuracy of social tracking performance (Probasco, 1969; Rothe, 1973; K.U. Smith, 1974; K.U. Smith & Smith, 1970; Yates, 1963), just as they do for individual tracking performance. For example, a feedback delay of 0.2 second decreases social tracking accuracy by 50 percent. As with individual behavior, the integrity of social behavior likewise relies on effective control by each partner of the temporal and spatial qualities of sensory feedback generated during the social tracking process.

8.5.6 Social Tracking in Group Interaction

Because of the introduction of additional sources of sensory feedback to control, the demands and complexity of social tracking in groups involving more than two people rapidly escalate (K.U. Smith, 1974; K.U. Smith & Smith, 1973).

8.5.7 Social Cybernetic Basis of Cognitive Behavior and Communication

Interactive social communication, with its pronounced motorsensory feedback control demands, is central to all modes of cognitive behavior and represents the principal determinant of effective learning of cognitive skills (K.U. Smith, 1974; T.J. Smith & Smith, 1987a, 1988b).

8.6 SOCIAL CYBERNETICS RESEARCH SINCE 1994

Since the above review, further research using the social cybernetics model has been conducted on the feedback control relationships during social interaction and teamwork.

8.6.1 Feedback Control Compliance During Parallel-Linked Social Tracking

The influence of a wide range of ergonomic design factors on compliance has been investigated under laboratory conditions. Building on previous research conducted by Sauter and Smith (1971), two-person teams performed a cooperative computer-mediated task that involved both feedback and feedforward control in order to steer a simulated object through a complex path. Each team member used a joystick to control 50 percent of both the horizontal and vertical positioning of the simulated object during parallel-linked social tracking, requiring team members to coordinate their control inputs to perform the task. When control inputs to the object were delayed for only one team member, the team member without delayed control was able to compensate, showing that teams adapt to feedback control disparity by shifts in workload to the team members less burdened with feedback control perturbations (Li, 1998; T.J. Smith et al., 1998). These findings provide support for the joint feedback and feedforward control processes involved in social cybernetics. The less burdened team member was able to detect the error differential resulting from the partner's control delay and compensate in a proactive manner.

In another study, parallel-linked control of an inertial object occurred in a simulated microgravity environment. Each team member was able to exert horizontal and vertical forces on the object through use of separate joysticks (Glynn et al., 2001). In an effort to augment compliant social feedback between team members, force feedback was provided to each team member based on the direction and amplitude of their fellow team member's joystick inputs. Force feedback was found to improve team performance, demonstrating the value of providing additional sources of social feedback regarding control inputs beyond what is normally available regarding system response during the parallel-linked mode of social tracking.

In an investigation of team-controlled rest break activity, teams performed a joint computer-mediated task that required regular exchanges of information and text entry on separate computer workstations while also meeting a target level of rest break activity over the work period. Separate experimental conditions were used to examine parallel-linked and serial-linked control of short rest breaks. Parallel-linked control over discretionary rest break behavior was found to benefit productivity and wellbeing but also increased the demand for work coordination (Henning et al., 1997). Results from this study demonstrate the importance of team coordination for both team effectiveness and individual wellbeing.

8.6.2 Delayed Feedback in Serial-Linked and Mutual Social Tracking

To further investigate the impact of delayed multimodal feedback in social tracking, a series of studies were conducted using video disk technology as a means to systematically introduce audio delays and/or video delays in communications between two team members located in separate sound-isolated rooms. These experiments provided evidence for the critical nature of social control dynamics regardless of the mode of social tracking or modality through which feedback is provided. In one experiment, two-person teams performed the NASA Multi-Attribute Task Battery (MATB) that was adapted to require serial-linked social tracking. Audio delay of the voice commands was used to systematically perturb control of the task. Delays longer than 2 seconds were found to have nonlinear deleterious effects on team performance (Armstead & Henning, 2007).

In another study, two-person teams performed a simulated fire-fighting task that was adapted to require serial-linked social tracking. Audio delays were introduced in various schedules (e.g., fixed versus variable) to determine if practice on some schedules would promote better team learning or adaption. Results showed that practicing under longer feedback delays accelerated team training (Dove-Steinkamp & Henning, 2012), a finding that is consistent with related research showing that other types of feedback control perturbations also benefit team training (Gorman et al., 2010). Data from the simulated fire-fighting task were also analyzed to determine if social tracking was relevant to team outcomes other than performance; namely, stress. Results showed evidence of effects at the team-level analogous to individual-level effects in the job demand control model of stress (Karasek, 1979) as well as effects of team-level coordination, providing support that the emergent properties of teams can have a significant impact on the stress levels of individual team members (Calabrese & Henning, 2013).

Effects of delaying both audio and visual feedback on social interaction was investigated using video disk technology to experimentally delay (1 s) both audio (speech) and visual (upper body) feedback between two individuals located in separate rooms while they conversed with each other on assigned topics. In general, even short communication delays are known to have a perturbing effect on social interaction. These short imperceptible audio-visual delays were found to benefit perception of the emotional state of fellow participants in the first 10-min conversational period. However in the second 10-min conversational period, participants experienced increased frustration without incurring this same benefit (Powers et al., 2011). In a related study, participants conversed in either mixed-race or same-race dyads. Whereas mixed-race dyads reported greater anxiety and less interest in contact under audio-visual delay, same-race dyads reported less anxiety under delay conditions than in real-time (nondelayed) conversation (Pearson et al., 2008).

8.6.3 Augmented Team Cognition

Augmented cognition refers to a focused effort in the field of human factors and ergonomics to develop systems that significantly augment an operator's cognitive performance through use of physiological assessment of operator state in real time. Most research efforts in this area have been guided by linear information processing models, and attempt to address presumed bottlenecks to human information processing that would limit operator performance. A behavioral cybernetic model for augmented cognition was introduced by T.J. Smith and Henning (2005) as an alternative, in which the motor-sensory control of individual operators is augmented to benefit cognitive functioning. Additionally, measures of social-relational tracking were suggested for possible use in systems designed to augment team cognition; for example, using such measures to help teams establish the best pace for teamwork activities (Henning et al., 2005; T.J. Smith & Henning, 2006). The feasibility of this behavioral cybernetic approach to augmenting team performance had been demonstrated earlier when synchronicity in heart rate variability between two team members was used to create task-integrated feedback in real time that team members then used successfully to pace a projective tracking task involving parallel-linked control (Henning et al., 2000). In a later study, a communication delay between team members located in separate rooms was systematically introduced in an attempt to isolate physiological changes most closely associated with social-relational tracking for use in systems to augment team cognition (Henning et al., 2007).

8.6.4 Social Cybernetics in Participatory Ergonomics Programs

Principles of feedback control play a crucial role not only in small social systems, such as a team, but also in larger social systems, such as work organizations. As part of the Total Worker Health™ initiative by the National Institute for Occupational Safety and Health (NIOSH), the Center for the Promotion of Health in the New England Workplace and researchers from the University of Connecticut and University of Massachusetts Lowell have been involved in a multidisciplinary research-to-practice effort to introduce integrated workplace interventions to benefit worker health protection and promotion. Social cybernetics principles were applied by the first author to help guide the development of a programmatic approach based on participatory ergonomics. This program arranges for frontline employees to regularly participate in the planning and design efforts for these workplace interventions (Henning et al., 2009b). This participatory approach provides for organized communication from frontline employees to management regarding the need for interventions, as well as feedback from the organization to employees regarding interest and efforts to intervene. An Intervention Design and Analysis Scorecard (IDEAS) planning tool was developed to provide employee design teams with a structured approach to design and propose workplace interventions (Robertson et al., 2013; Henning & Reeves, 2013). Successful field-tests of the IDEAS tool and the overall programmatic approach were guided, in part, by the behavioral cybernetic model for organizational learning introduced by Haims and Carayon (1998). A survey tool to aid management in tracking the health of participatory ergonomics programs (Matthews et al., 2011) was adapted for program evaluation. Social tracking relationships in management systems have also been shown to impact the effectiveness of safety systems more generally (T.J. Smith & Larson, 1991; T.J. Smith, 2002).

8.7 DESIGN IMPERATIVES FOR HOMEOKINESIS AT THE TEAM LEVEL

It seems likely that homeokinesis at the team level may be as critical to the effective control of team behaviors as homeokinesis is at the individual level for the effective control of individual behaviors. Homeokinesis at the team level would occur when team members establish and maintain an adequate level of yoked social tracking behavior necessary for team members to function effectively as a social system. Such yoked behaviors would have significant reciprocal effects on the physiological functioning of all team members.

One reason homeokinesis at the team level may be critical to effective team function is that responding to task demands as a team depends on the effective use of the team's resources. The availability of team resources, such as the readiness of team members to engage in parallel social tracking in response to an immediate task demand, would require that individual team members are already tracking the task situation together via yoked motorsensory control. Establishing homeokinesis at the team level may also be necessary for desirable forms of mutual control to emerge as systems phenomena; for example, creative brainstorming as a team. In contrast, a lack of homeokinesis at the team level would be detrimental to team performance because the team would be unable to mobilize and coordinate its own resources effectively. Therefore, one human factors design imperative for effective teamwork is to specify the nature and extent of interdependent task activities necessary for achieving and maintaining homeokinesis at the team level.

A second human factors design imperative regarding homeokinesis for effective teamwork is to specify the types of activities team members should be involved in when not actively engaged in teamwork activities involving yoked motorsensory control. Such activities are necessary so that individual team members can regulate their own behaviors effectively during slow or downtime periods that lack interdependent teamwork tasks.

A third human factors design imperative regarding homeokinesis for effective teamwork is to systematically design team tasks and individual tasks to support smooth transitions between them from the standpoint of homeokinesis. This requires that team members not actively engaged in a mode of social tracking must be sufficiently engaged in alternate tasks that are selected and designed to make it possible for team members to temporarily function independently while also tracking teamwork activities. Otherwise, individual team members will have difficulty reengaging with interdependent tasks and social tracking activities when needed.

Together, these three human factors design imperatives offer a more comprehensive systems approach to the design of teamwork than is normally considered. The focus of human factors design efforts is expanded beyond the interdependent tasks that represent core team activities. Consideration of design factors to promote homeokinesis at both the team and individual levels and through the transition periods as well as in complex combinations is offered here as a coherent systems design approach for managing a key source of team performance variability.

The nature and extent of homeokinesis at the team level versus homeokinesis at the individual team member level impacts the availability of team resources in specific ways. In general, homeokinesis at either the team level or individual team member level can be considered as two primary means of creating resources during teamwork. While multiple resource models have been helpful in examining human capabilities and limits (e.g., Wickens, 2002), there has been no clear mechanism offered to account for how these resources are managed or replenished during teamwork. For example, crew resource management techniques for training high-performance teams are largely limited to prescribing standard ways that individuals should behave as team members, such as being more assertive when needed. There is also training on standard ways to handle problems through use of stepwise approaches, such as first recognizing a problem, then defining it, then identifying probable solutions, and then implementing a solution. The limited nature of these approaches may partly explain why a recent metaanalysis of 28 crew resource management training studies revealed a lack of widespread empirical support for the efficacy of crew resource management (Salas et al., 2006). It can also be noted that only a few of these training studies emphasized aspects of crew coordination that would reflect modes of social tracking.

Human factors approaches need to provide a level of design specificity necessary to promote homeokinesis at both the team and individual team member level. For example, one design recommendation for a specific team task might entail predictable periods of parallel-linked social tracking by the whole team as a means to regularly transition to homeokinesis at the team level. Team members could also regularly participate in consensus decision-making activities or engage in other joint activities with some team members. The division of labor during parallel-linked tracking has been shown to dictate the nature and extent of teamwork involved (Sauter & Smith, 1971); for example, control can be divided up equally so that all team members must work together to address the parallel task at hand. Additionally, serial-linked tracking activities can be employed to maintain close social tracking relationships among smaller numbers of team members over long periods of time. Imitative social tracking activities can involve job shadowing or interning for progressive training purposes. Individualized (non-team) tasks could include tracking team task activities by monitoring communications within the team or by preparing for future teamwork activities in ways that maintain yoked motorsensory control and readiness for upcoming teamwork demands.

Monitoring of individualized task activities by supervisors would help assure that these activities are engaging enough for homeokinesis, promote the needed readiness for engaging in future teamwork activities, and that switching between individualized task activities and teamwork activities is not unduly stressful. The popularity of dashboard systems to assist the management in monitoring social and individual activities to better guide or steer organizational behaviors suggests that many organizations already recognize the need for dynamic social tracking activities when managing sources of team performance variability. Therefore, the human factors design imperatives introduced above may be relatively easy to assimilate into existing management practices.

Consideration of the above human factors design imperatives and translation of social cybernetic principles can occur in the context of well-established human factors design techniques for system development (e.g., Chapanis, 1996). To begin with, a task analysis could provide a complete listing of all of the tasks that need to be accomplished. These tasks can then be allocated according to the human factors design imperatives for homeokinesis listed above. Similar to the challenges found in allocation of functions between human operators and automated machine systems (T.J. Smith & Smith, 1988b; T.J. Smith et al., 1995), tasks are allocated depending on the homeokinetic needs of the whole team, a subgroup of team members, or the individual team members. Functional flow analysis combined with timeline analysis can then offer a more systematic approach for allocating task activities to meet homeokinetic needs at any moment in time.

8.8 ASSESSMENT OF HOMEOKINESIS AT THE TEAM LEVEL

The design imperatives introduced above all center around establishing and maintaining teamwork in relation to homeokinesis. However, the level of homeokinesis at the team level may not be readily apparent to an outside observer or even to the team itself. Therefore, an objective means of assessing homeokinesis at the team level could greatly benefit the human factors design efforts in system development and would also benefit human factors research on the sources of performance variability in teamwork.

As explained earlier, there are numerous reciprocal effects of motor activity on physiological functioning. Team members' interdependent task behaviors during social tracking and teamwork therefore have predictable reciprocal effects on the physiology of each participating team member due to yoked motorsensory control,

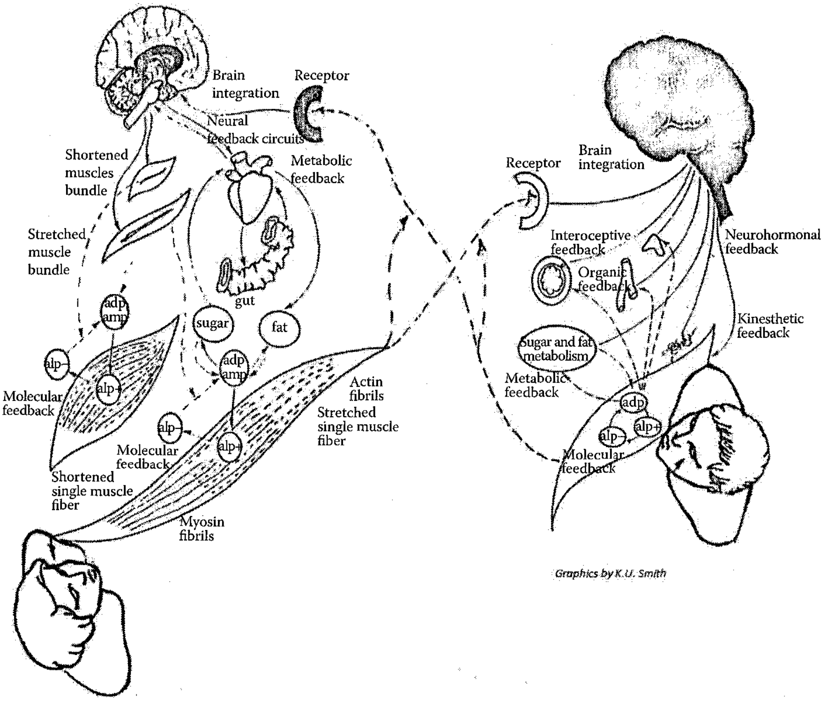

FIGURE 8.3 The reciprocal effects of yoked motorsensory control on the physiological functioning of two team members during social tracking.

as depicted in Figure 8.3. The term "physiological compliance" was originally introduced to represent the way that control over the participants' physiology becomes integrated during social tracking (T.J. Smith & Smith, 1987a). In as much as social physiological compliance reflects yoked motorsensory control during teamwork, it should be possible to detect this in the physiology of team members in order to monitor social-relational dynamics on a continuous basis. For example, sustained mutual control over social behavior during teamwork would be expected to be accompanied by an extended period of social physiological compliance among team members. Efforts have been made to test candidate physiological measures as predictors of subjective and objective team performance outcomes as well as participant ratings of their own teamwork effectiveness. For example, when team members used joysticks in a computer-mediated task to guide a simulated object through complex path, Henning et al. (2001) found that several social physiological compliance measures based on cross correlation and weighted coherence analyses of breathing pattern, electrodermal activity, and heart rate variation were each predictive of team tracking performance. An analysis of data from the same study also showed that social physiological compliance predicted team members' ratings of performance effectiveness (Gil & Henning, 2000).

Social physiological compliance would also appear to be a good candidate measure for assessing homeokinesis at the team level in task contexts. This could be helpful in determining which aspects of task design promote homeokinesis at the team level or place the team at risk for increased performance variability if homeokinesis at the team level is limited or absent. There is some evidence that social physiological compliance may be episodic during teamwork (Henning et al., 2009a), suggesting that maintaining high levels of homeokinesis at the team level for long periods may be difficult for teams and/or even counterproductive to teamwork. One can speculate that long-duration team tasks may require alternating periods in which either homeokinesis at the team level or individual team member level dominates in order to minimize performance variability or to prevent team burnout.

The nature and the extent of social physiological compliance and homeokinesis at the team level can also be expected to be impacted by the mode of social tracking team members are engaged in. Highly synchronous changes in the physiological states of team members can be expected during imitative social tracking because the motor behaviors of the participants are closely matched and synchronous, resulting in a very high level of team homeokinesis. In the case of parallel-linked social tracking, social physiological compliance and homeokinesis at the team level could vary depending on the degree to which team members engage in any of the following activities: close coordination of control inputs to the system, shared motor-sensory tracking of system responses to control inputs, and social tracking of the activities of fellow team members, including any communications between team members about the task at hand or about social-relational tracking itself. In the case of series-linked social tracking, social physiological compliance can be expected to vary depending on the nature and extent of serial communication behaviors that are necessary among team members for either control actions or for tracking system response to these control actions. Time delays in any of these communications would be cumulative in serial-linked social tracking, requiring that any substantial delays be factored in to prevent gaps in joint activity that might become problematic for maintaining homeokinesis at the team level.

In another study of social tracking, two-person teams performed the projective tracking task described above that involved steering a simulated inertial object through a complex path. Unexpected changes in the vertical and horizontal control dynamics of the input joysticks occurred (e.g., the sudden inversion of the vertical control inputs) that required the team to adapt quickly to these changing task demands. Social physiological compliance was found to be a significant predictor of how well a team would perform immediately following these unexpected events (Henning & Korbelak, 2005). These results provide further evidence that physiological compliance serves as an indicator of mutual control by demonstrating improved ability of team members to recover from disruptions once physiological compliance during teamwork is established.

Patterns of social physiological compliance were studied in a preexisting four-person team of graduate students who met weekly for research group meetings over two months. As the students planned their research project together, social physiological compliance was examined in a pairwise fashion between team members to match up with conversational exchanges. Subjective ratings of team performance at the end of each meeting were found to be negatively correlated with increased social physiological compliance (Henning et al., 2009a), replicating the findings of a study on married couples engaged in difficult counseling sessions (Levenson & Gottman, 1983).

Contrary to the positions and evidence presented in this chapter thus far, these results suggest that high levels of physiological compliance during social interaction may result in negative experiences. One possible explanation is that team member dissatisfaction or the observed negative affect during marital interaction do not necessarily imply the absence of effective mutual control during social interaction. Rather, team members may have slightly negative reactions to the loss of individual control that is inherent to periods of social physiological compliance. It is also possible that sustained high levels of homeokinesis at the team level are problematic and contribute to performance instability whenever individual team members are unable to take a break from teamwork or have insufficient time to fulfill tasks not involving teamwork.

Recent teamwork research provides empirical support for both of the interpretations offered above. One research study reported direct, positive relationships between social physiological compliance, measured through heart rate variability and respiratory sinus arrhythmia, and team performance on a combat video game (Elkins et al., 2009). More recently, Chanel et al. (2012) also found evidence that social physiological compliance measured as weighted coherence of breathing patterns was indicative of rich social interaction during more challenging task periods in a maze videogame. Additionally, social physiological compliance in two-person teams, based on ventilatory drive measures, was predictive of objective team performance in a shared decision-making marketing and production task (Bizarro, 2013). In this latter study, those teams able to maintain a high level of social physiological compliance made production and marketing decisions that resulted in higher simulated profits than teams that did not maintain a high level of social physiological compliance. These studies provide empirical evidence that social physiological compliance does have a positive impact on objective team performance.

In combination, the above-mentioned studies lend support to the conclusion that social physiological compliance can serve as an indicator of the mutual control over interdependent task activities as predicted by the social cybernetic model of teamwork. Physiological compliance measures have the potential to provide objective measures of team coordination that are not possible to obtain with subjective measures of team coordination and may also provide a means of studying homeokinesis at the team level.

8.9 CONCLUSIONS

Social cybernetic principles offer a coherent systems approach for conceptualizing how behavior is organized and controlled in teamwork. The three distinct modes of social tracking that make up all forms of social interaction can be used to systematically analyze the control dynamics involved in specific forms of teamwork. Empirical studies show that design factors that affect feedback control or feedforward control in social tracking can significantly impact social and team performance variability. Therefore, identifying the context-specific design factors in teamwork tasks that determine feedback compliance in the social tracking activities making up these tasks represents a scientific way to control for sources of team performance variability. Another key cybernetic consideration in the design of team tasks and task environments is maintaining homeokinesis at both the team and team member levels, resulting in a set of human factors design imperatives that can be met through use of established system development methods in the field of human factors. For example, allocating tasks to the team as a whole or to individual team members would be done more systematically so that transitioning between interdependent team tasks and individual tasks is not problematic. Social physiological compliance based on shared physiological changes, such as the synchronization of heart rate variability among team members, reflects yoked motorsensory control among team members and provides a potential means for assessing social-relational tracking and homeokinesis at the team level. Application of social cybernetics principles in program development efforts at the organizational level has been helpful in minimizing team performance variability as well as optimizing the wellbeing of individual team members.