CHAPTER 20

Mental representations as an underlying mechanism for human performance

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Abstract: This chapter presents a theoretical framework, which is supported by empirical evidence, where changes in human performance are accounted for by changes in mental representation structure (MRS). More specifically, the knowledge base, represented in the form of mental representations, controls the perceptual, cognitive, and motor systems when interacting with the environment. Once this interaction induces pressure, changes in the MRS lead to respective changes in the function of attention, anticipation, long-term working memory, the control system, and the motor systems. Such changes can be detected via both overt and covert behavior of the human system. This chapter presents the theoretical frameworks and accompanies them with graphical illustrations.

Keywords: representation; motor learning; variability; motor control; memory

Introduction

The structural components of human performance, such as emotional processes (i.e., feelings, mood), cognitive processes and structures (e.g., knowledge architecture, long-term working memory), motor processes (coordination, endurance), and the neurophysiological basis of these structural components (i.e., activation of cortical areas) have been studied independently. Our attempt is to integrate these structural components into a unified theoretical framework that enables a better understanding of human performance, which allows for generating applications that share scientific validity. Our working assumption is that every action made by humans is a consequence of response selection, whether intentional or unintentional. By definition, response selection indicates adaptive behavior based upon the capacity to solve problems. Cognitive processes and mental operations underlie this “behavioral effectiveness.” The effectiveness of these processes consists of the richness and variety of perceptions processed at a given time; that is, the system’s capacity to encode (store and represent) and access (retrieve) information relevant to the task being performed (Tenenbaum, 2003). Because tasks vary with respect to unique characteristics and requirements, it is assumed that the nature and integration of perceptual-cognitive components required for decision making and action execution are also unique, though they may share similar architecture when the tasks include common elements. From an information-processing perspective, motor

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behaviors consist of encoding relevant environmental cues through the utilization of attentional strategies, processing information through an ongoing interaction between long-term and working memory, making action-related decisions, and executing actions while leaving room for refinements and modifications.

Under pressure, changes in each functional component may occur. These changes can affect the perceptual components, continuing with the cognitive components, and ending with the motor system. However, each of these components can be understood as a decision-making component, which has consequences for the final decision and action to be taken. To capture changes in the perceptual-cognitive–motor linkage under varied conditions of pressure and evoked emotions, we must use research paradigms that integrate the cognitive structure components and processes (cognitive appraisal), emotional system, and the self-regulation structure (i.e., emotional control, motivation control, attentional control, etc.). Both idiographic and group concepts are presented, allowing for detection of a collapse in the perceptual-cognitive linkage under altered emotional states, and their subsequent effects on the motor system.

**Decision-making processes as a conceptual framework for studying actions**

In most cases, the motor system responds to intentional cognitive processes, which are goal-directed, and thus rely on mental regulation. These mental regulations take into consideration person-related characteristics, task demands, and conditions under which the task is carried out (e.g., environment) (see Schack and Hackfort, 2007 for review). According to this concept, every action consists of some kind of mental representation network, which not only consists of action representation, but also relies on a mental schema with neural pathways to information labeled as emotions, actions, and coping plans. Even when motor movement becomes automated, intentions still guide actions through mental representation, which in this case are not extensively activated, allowing the perceptual-attention–cognitive system to work in parallel. Thus, one should consider the person-task-environment within a system framework where social and physical systems must be taken into consideration for capturing the perceptual-cognitive–motor linkage (Schack and Hackfort, 2007). Figure 1 captures the basic framework of action theory (Nitsch and Hackfort, 1981; Newell, 1986; Nitsch, 2004). One should consider all components of the system as dynamic components, which alter in time and space. However, changes in restructuring the neural network defined as a schema take time, and depend largely on the amount and frequency of exposure to similar tasks and environmental conditions.

An important tenet of intentional (goal)-directed motor action assumes that voluntary movements are stored in memory and contain anticipated consequences in the form of neural schema, and thus are of extreme relevance to the control of movement production (Schack and Tenenbaum, 2004a, b). Thus, when an action must be initiated, planned, and executed, the sensory system, mainly the visual system, is guided by the neural schema through long-term working memory (Ericsson and Kintsch, 1995). Access to long-term working memory consists of two routes: a knowledge-based route and a retrieval-based route. These allow the neural system to control and guide the visual system efficiently under conditions that vary in mental, temporal, and environmental pressure. The control of the visual system allows anticipatory decisions to be made, and consequently actions to be retrieved from long-term memory (LTM). Furthermore, knowledge structures in the form of mental representations not only allow efficient control over decision making and action, but allow the perceptual-cognitive–motor linkage for anticipated changes to occur once fast changes in the environment necessitate such alteration. When such representations are nonexistent, alternative decision plans and actions are likely to result in failure of the motor system to respond appropriately (see Tenenbaum, 2003 for details). Furthermore, mental representations consist of action plans associated with affective and motivational components, such as self-efficacy. If an appropriate action is retrieved, it may still
be interfered with once self-efficacy and emotions are deemed nonoptimal. Assuming that a knowledge base in the form of mental representations guides the motor system, and at the same time is fed by it, several decisions must be made under varying environmental conditions. These perceptual-cognitive decisions are presented as a logical sequence in Fig. 2.
Each decision in the sequence is related to a general plan stored in LTM, but may have different consequences if inappropriately solved. The first decision is related to the visual system; its goal is to direct the visual attention to the cues deemed essential for response selection. Thus, the first decision to make is “where to gaze, and to what cues to attend?” When the environmental cues are fed forward to the neural system, the mental representation network (i.e., schema) initiates some elaboration in the form of neural activity, which results in anticipating upcoming events with certain probability (Tenenbaum and Lidor, 2005). The main question here is, “what should be anticipated given the situation?” Anticipation is the most crucial component in the sequence, because it activates alternate and competing solutions from LTM in the form of response selection. Thus, the decision here is “what alternative solution should be sent to activate the motor system, and which one to leave as an alternative?” At this stage, the motor system is initiated, while in some cases this system remains “on alert” anticipating possible environmental alterations, and ready to respond to the question, “what alternative response must be selected to replace the previous response?” The last decision is related to the timing of the response, which is crucial in dynamic environments. Once a correct decision has been selected, activation of the motor system with improper timing will result in system failure. The decision here is, “when to activate the response selection in the motor system?”

The five-step sequential decision making is classified into two main components. The sequence offered here however, allows for an easy detection of action breakdown, but does not infer ultimate dependence of each preceding stage on the proceeding one. One component is related to decision making regarding environmental decisions. These components consist of the visual system and the visual strategy used to gather information, thus consists mainly of the perceptual system. The second system consists of mental and cognitive operations, which process the information gathered by the perceptual system, and fed forward via working memory for response selection (see Fig. 3). The neural schema controls the performance of the two systems.

![Control Mechanism Diagram]

Fig. 3. Perception-action and cognitive components related to action guided by mental representation network (schema).
Linking perceptual-cognitive systems to the motor system

Under pressure, which may be emotionally induced, or result from demanding temporal conditions (e.g., when a batter must respond to an incoming baseball pitch), the perceptual-cognitive systems (A and B in Fig. 4) and the control system (E in Fig. 4) change their operational mode. More specifically, attention narrows (Landers, 1980), limiting the cognitive processing system to operate under goal-directed orientation while interfering thoughts compete for attention (Abernethy, 1993). The resulting collapse of the control system is unable to keep the perceptual-cognitive–motor flow intact. Consequences of the collapse are seen in a delayed response, increased response-selection errors, and diffuse and non-proficient motor responses. Once pressure is perceived as debilitating, usually by telic-oriented people (e.g., goal-directed and avoiding risk-taking) facing pressure, which alters their hedonic tone into experiencing anxiety (see Apter, 1982), the perceptual schema is no longer valuable resulting in the well-established LTM schema to operate under nonoptimal conditions. As a result, the control schema suffers collapse. However, under pressure conditions, which are typically perceived as challenging by paratelic-oriented people (e.g., taking risks and challenges; Apter, 1982), there is no collapse of the perceptual, cognitive, and control systems schema. Thus, the systems function efficiently by providing the necessary environmental information needed for response selection and coordinated motor action. Figure 4 portrays these linkages considering the perceptual, cognitive, and motor operating systems separately, but as depending on each other. It should be noted that the control system (Fig. 4(E) is viewed as a system that controls all

![Fig. 4. A proposed scheme linking perceptual-cognitive components to the motor system using mental representations as underlying this linkage.](image-url)
other systems, though graphically shown as one component in a sequence. It should also be noted that the systems illustrated here function differently under automated mode of operation, but they still are activated and functional (i.e., operate under unconscious control), especially when the system shifts from unintentional to intentional mode of operation. We also claim that impaired perceptual, cognitive, and motor processes and responses can be observed and detected through using common research paradigms (Abernethy, 1993; Tenenbaum and Lidor, 2005), which can be matched with their underlying mechanisms in the form of impaired schemata (Schack and Mechsner, 2006). These schemata are linked to the emotional centers in the brain (Hatfield and Kerick, 2007), and when primed they activate the associated neural network, which holds particular information labeled “emotion” (see Bower, 1981). This conceptual framework constitutes Fig. 4.

Changes in visual attention and information processing under pressure

To verify how the system works interactively, we must study how emotion and affective states, which vary in valence and intensity, provoke neural changes in the brain pathways and centers, while simultaneously observing behavioral changes. For example, retrieval of information is facilitated when context during retrieval extract the same emotional states experienced when encoding (affect-state dependence) (Bower, 1981). This linkage, and its relation to “knowledge structure,” has not been studied in performing perceptual-motor tasks, particularly under pressure. Emotions are linked directly to memory and mental representation, thus directly activating mood consistent event files in memory and event-related parts of knowledge structures. When heeding information, subjects selectively pay attention to cues that are congruent with current emotional states (affect-congruent attention). In other words, direction of attention is influenced by the emotional content of the encountered stimuli. Positive or negative moods increase attention and the amount of rehearsal of mood-congruent facts, which results in stronger associations with positive or negative information, respectively. This notion must be further studied with respect to pressure conditions and skill level of the performer. In addition, how emotions and concentration vary when performers of different expertise levels perform a task is of interest.

Emotions can be viewed as memory units (Bower, 1981). They are components linked to the memory system that facilitate access to mental representations associated with targets of judgment (Forgas, 1991). Due to prior associations, innate and learned environmental situations activate particular emotion nodes stored in the memory. This activation spreads throughout neuronal circuits to mental representations of events associated with that emotion, influencing encoding and retrieval of material, as well as the valence of judgments of people, events, objects, and behaviors (Bower, 1991). Emotions are activated by re-experiencing the emotion, or by activation of any of their links (Barry et al., 2004). The stronger the activation of particular emotional nodes, the greater the mood-congruent effect. When emotions are strongly activated, emotion-congruent constructs (e.g., concepts, words, themes, and rules of inference) become primed and available for use, which brings into readiness certain perceptual categories, themes, or ways of interpreting the world congruent with current emotional states. In affect-priming terms, an emotion node spreads activation throughout the memories to which it is connected, increasing the chance that those memories will be retrieved (Bower, 1981).

This is important for capturing human performance because perception and action are based on the same representation structures (see coding theory; Prinz, 2005). Such an emotion, based activation of representation, affects the perception of the actual situation, and the focus of attention. Therefore, there is the risk that a “vicious circle” (a self-perpetuating process that returns to its starting point with no improvement from when it was begun) between threatening stimuli and negative emotional states activates event files, representation structures, and focuses attention on threatening stimuli, which most probably results in performance decrement.
What changes under conditions which vary in...

- Emotional/Aroused Activation?
- Temporal Occlusion Constraints?
- Both?

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<td>Attentional Width</td>
<td>How many choices left?</td>
<td>How much information is fed-forward?</td>
<td>How limited is the system to change?</td>
<td>Where is the &quot;point of no return&quot;?</td>
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<tr>
<td>Visual Scanning</td>
<td>How confident one is in these choices?</td>
<td>What information is ignored?</td>
<td>What channels of information processing are blocked?</td>
<td>Is pressure an &quot;alert system&quot;?</td>
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What are the underlying neural mechanisms of these changes?

Fig. 5. Consequences of pressure on visual attention, processing information, and decision alteration.

**Figure 5** illustrates possible behavioral outcomes that may occur under pressure conditions associated with emotions. We note that the emotion-associative schema is not presented in this figure, because of the limited evidence we present next. However, pressure affects visual scanning, usually in the form of narrowing the attention span, resulting in errors, which are attributed to information omission. When pressure and/or emotions affect the visual attention system, a collapse of all other systems is evident (see Fig. 6; components A, B, C, D, and E are derived from Fig. 4). This collapse results from a limitation in the information fed-forward, which is not comprehensive enough to make a reliable response selection. Furthermore, this is linked directly to alterations in the affective state, which takes the form of an increase in anxiety and a decrease in self-efficacy (Tenenbaum, 2003). Thus, the motor system is affected directly by nonoptimal emotional states, and indirectly through the effect of pressure and emotional states on the perceptual-cognitive system, resulting in a delayed response, inappropriate response, and uncoordinated action. We claim that these can be detected while observing respective changes in the mental representation schema.
(see Figs. 7 and 8). In this line of conceptualization, anticipatory failure under high-pressure and nonoptimal emotional states result in limited choices for response selection, and decreases in confidence of these choices resulting in poor decision making and collapse of components C, D, and E (see Figs. 4–8).

Assuming that both the visual and anticipatory systems remain intact under nonoptimal conditions, the processing of information, however, may experience functional difficulties. Vital to the framework of expert performance is the cognitive control structure that governs information processing and task execution. Central to the optimal functioning of the cognitive control system is the proper allocation of attentional resources (Wulf, 2007). The fundamental assumption underlying the allocation of attention is that successful task performance is dependent upon attending to certain relevant information, while ignoring others (Lewis and Linder, 1997; Beilock and Gray, 2007). As such, an individual’s focus of attention can have important consequences for the management and allocation of information-processing resources.

Under pressure, performance breakdown can result from compromises and disruptions to the attentional mechanisms that underlie skill execution. Understanding the impact of pressure on performance requires consideration of the attentional demands imposed by the task as well as consideration of skill level (Abernethy et al., 2007). Recent literature on “choking under pressure” has proposed two main attentional theories that seek to describe the mechanisms that account for pressure-induced performance failure (Wine, 1971; Baumeister, 1984; Lewis and Linder, 1997; Beilock and Carr, 2001). Distraction theories give an account of performance breakdown on tasks that rely heavily on working memory and fact retrieval (i.e., cognitive tasks) (Beilock and Carr, 2001). Explicit monitoring theories, in contrast, account for disruptions in tasks that are largely automated (i.e., proceduralized) and motoric in nature (Beilock and Carr, 2001).

Based upon resource allocation models of information processing, distraction theories propose that performance failures result from attention being diverted away from task-relevant information (Wine, 1971). As a consequence, increased focus on task-irrelevant cues such as worries and consequences consume vital working memory and attentional resources. As specified by resource allocation models, attention and

Fig. 7. A theoretical schema under normal and pressure conditions — some neural linkages, which represent motor elements, are nonactivated under pressure. DM, decision making.
working memory are both limited in capacity (Schmidt and Lee, 1999). This limited capacity impacts the ability to handle information from the task and environment efficiently. Under pressure, attentional resources become divided between task-relevant and task-irrelevant cues leaving inadequate working memory and attentional capacity to attend fully to the primary task to the extent required for successful performance (Hardy et al., 1996). As a result, compromises to attentional resources by task-irrelevant information lead to a disruption in performance.

The distraction theory best accounts for performance disruptions in tasks that place heavy demands on attention and working memory capacity. As a result, academic- or cognitive-based tasks have typically been the primary source of investigation supporting a distraction account of pressure-induced performance failure (e.g., Wine, 1971; Nottelman and Hill, 1977; Deffenbacher, 1978; Beilock et al., 2004b). However, any task that utilizes online attentional resources is potentially susceptible to pressure-induced compromises to attentional capacity. Such tasks may include decision-making, problem-solving, or reaction-time tests (Lewis and Linder, 1997; Beilock and Gray, 2007). Sports that rely heavily on such processes are likely to be most susceptible to a distraction account of choking.

Not all skills, however, place large demands on attention and working memory capacity. Specifically, high-level motor skills comprising of proceduralized knowledge do not require constant online attention, and run largely outside of working memory (Fitts and Posner, 1967; Beilock et al., 2002). Therefore, high-level skills that are assumed to be automated, requiring little online attention, should be relatively robust against conditions that draw attention away from task execution (Beilock and Carr, 2001). As a result, explicit monitoring theories propose an alternate attentional mechanism to account for pressure-induced performance failure for heavily proceduralized skills.

According to the explicit monitoring theory, performance pressure increases self-focused attention to the step-by-step processes of skill execution (Lewis and Linder, 1997). For highly proceduralized motor tasks, this shift in attention to the details of movement disrupts the automaticity of well-learned skills, resulting in

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**Fig. 8.** Theoretical schemas for anticipatory, processing, and execution processes under normal and pressure conditions — some neural linkages, which represent motor elements, are nonactivated under pressure. DM, decision making.
performance breakdown (i.e., choking) (Fitts and Posner, 1967; Baumeister, 1984; Beilock and Gray, 2007). The tenants of explicit monitoring theory are anchored in both self-awareness and skill acquisition theories (Hardy et al., 1996; Lewis and Linder, 1997). The assumption that pressure increases self-focused attention draws on the idea that task importance becomes more salient under pressure. In an attempt to ensure correctness of movement, attention is turned inward toward monitoring the processes of skill execution (Baumeister, 1984; Lewis and Linder, 1997). Research in the self-awareness literature offers support of this assumption as situational factors, such as audience pressure, competition, ego-relevance, and reward and punishment contingency, have been shown to increase pressure and self-focus (Baumeister and Showers, 1986; Lewis and Linder, 1997).

The disruptive nature of skill-focused attention on performance is based on the tenants of skill acquisition theory (Lewis and Linder, 1997). As athletic skill develops, athletes progress through different phases of skill acquisition (Fitts and Posner, 1967). Each phase is characterized by differences in both attentional requirements and cognitive control structures (Beilock and Carr, 2001). At the beginning of skill acquisition, skill execution is governed by slow, declarative, and attention-demanding cognitive processes. However, as skill develops through practice, skill execution becomes governed by fast, automated, procedural knowledge that runs largely outside of attention (Fitts and Posner, 1967). It is these highly automated skills that suffer from increases in self-focused attention brought about by performance pressure. Baumeister (1984) suggested that the increased attention to the details of movements disrupts the automatic nature of skill execution through a return to more controlled processing, which is characteristic of earlier stages of skill acquisition. Numerous studies have found support for the contention that increased attention to skill execution harms performance in well-learned skills (e.g., Kimble and Perlmuter, 1970; Langer and Imber, 1979; Wulf and Weigelt, 1997; Beilock and Carr, 2001; Beilock et al., 2002, 2004a).

While pressure can lead to disruptions in information processing caused by improper attentional focus, pressure and nonoptimal emotional states may also result in the slowing down of decision-making processes, response selection, and neurological signals to the motor system, resulting in a collapse of the motor system (D) and the control system (E). It is very rare that the motor system collapses under pressure without any precedent changes in the perceptual-cognitive systems. However, behaviors such as this are common when the motor skill is not well learned and acquired, and the motor schema, which supports the motor action, is not well inherited within the mental representation scheme. When the control system is impaired, all the systems suffer, and the mental representation schema is no longer securing smooth and efficient communications among the five systems (see Fig. 6).

**Changes in mental representations under pressure**

A method eliciting the cognitive (i.e., knowledge) structure in the form of mental representations was recently introduced by Schack and Mechmner (2006). They showed that performers who differ in skill level differ significantly in the structure and complexity of their mental representations' structure when asked to reflect on their actions. Once a performance collapsed under pressure (e.g., spectators, media, importance of the event, life threat, etc.), the mental structure of the performance remained stable, but that the level of mental control collapsed as it could not meet the environmental or inner requirements of the cognitive system. Mental control (e.g., self-regulation) broke down because the performers lacked the sufficient strategies required for coping under external stressful conditions.

In a dual-task auto-racing simulation, drivers who were highly anxious experienced an altered ability to acquire peripheral information at the perceptual level. At higher levels of anxiety, the identification of peripheral lights became slower and less accurate, and significant performance decrements occurred in central and peripheral tasks (Janelle et al., 1999). A variety of negative and positive emotions are also associated with
increased activation making it unclear whether it is the arousal or the valence of the emotions responsible for alterations on information processing.

Variation of psychological and physiological activation due to the stress response has an effect on the width of attention field, level of distractibility, amount of investment in controlled processing, and efficiency of attention processing (Janelle, 2002). These processes depend largely on the emotional experience (Mellalieu, 2003). In line with the research on specific psychological and physiological appraisal responses (e.g., Tomaka et al., 1997), it would be important to determine how the cognitive changes are influenced by different appraisals of stressful situations (i.e., threatening vs. challenging situation), and how these changes affect the motor system. Figures 7 and 8 assume that pressure and/or nonoptimal emotions result in collapse of the mental representation, which supports the motor program under normal operating conditions, and this mental collapse can be detected using behavioral and neural measures. One should note that in our conceptualized framework, appraisal and coping strategies in the form of self-regulation are part of the mental representation schema. When these schema are not well established, collapse of the perceptual-cognitive system and its linkage to the motor system is highly probable under conditions that evoke perceived pressure and elevated emotions.

Along with mental representations, the underlying knowledge structure that supports skilled performance also plays a role in resiliency to disruptions under pressure. Recent evidence suggests that learning environments can have a profound impact on how skill execution is controlled under pressure (e.g., Masters, 1992; Hardy et al., 1996). Specifically, the way in which knowledge is acquired may dictate the extent to which performance pressure leads to disruptions in skill execution. Traditionally, training systems are associated with deliberate attempts to learn, and are comprised of explicit instructions about the rules governing how a task is to be performed. The explicit instructions associated with conventional modes of learning lead to a large verbalizable knowledge base that is easily accessible and available for articulation. Such explicit knowledge about the complex chain of rules and techniques guiding performance, however, may be more susceptible to the debilitative effects of pressure as opposed to other types of knowledge structure.

According to explicit monitoring theories of choking, performance pressure turns attention inward toward the step-by-step processes of skill execution. This shift in attention toward the details of movement results in the disruption of automaticity resulting in performance breakdown (Baumeister, 1984; Lewis and Linder, 1997; Beilock and Carr, 2001). Masters’ (1992) Reinvestment hypothesis provides an account of the specific mechanism underlying this breakdown. According to Masters, the increased self-focus resulting from pressure causes performers to reinvest declarative/explicit knowledge acquired during early learning (Gray, 2004; Mullen et al., 2005). This “reinvestment” of explicit knowledge results in the “dechunking” of automatic control structures that normally run uninterrupted. Once the control structure has been dechunked into smaller sequences of independent units, each unit must be separately activated and run, increasing the likelihood of errors at each transition (Beilock and Carr, 2001). As a result, execution becomes slow and error prone; which is characteristic of novice performance.

The accumulation of explicit knowledge through conventional modes of learning may facilitate the likelihood of performance failure under pressure. In contrast, knowledge acquired through more implicit means has been shown to be more robust under situations of increased psychological stress (MacMahon and Masters, 2002). Implicit learning is characterized by the acquisition of knowledge without deliberate attempts to learn. In addition, implicit knowledge is largely unavailable to verbal report. The inability to access verbalizable knowledge associated with implicit learning has led some to suggest that implicitly acquired skills are less likely to be disrupted under pressure compared to more explicitly acquired skills (e.g., Masters, 1992). Under pressure, knowledge acquired
through implicit means would be inaccessible to be “reinvested” into skill execution, thus automaticity and performance would remain intact. Knowledge structure, therefore, can have important implications for the resiliency of the perceptual-cognitive–motor system to perform optimally under conditions that vary in situational demands.

**Changes in the motor system under pressure**

Under the framework proposed here, any collapse of the previous components underlying skilled performance will have a direct impact on the functioning of the motor system. However, to date, little research has examined the inter-relationship between these mediating components and the resulting motor response. While less is known about this inter-relationship, the direct impact of pressure and its associated emotions on movement behavior has been more thoroughly investigated. Research in this area has identified various biomechanical changes associated with stress and anxiety (e.g., Weinberg and Hunt, 1976; Beuter and Duda, 1985; Collins et al., 2001; Pijpers et al., 2003).

Findings revealed that feelings of anxiety and pressure can alter the characteristics of movement (Pijpers et al., 2005). More specifically, anxiety has been linked to movements that are less smooth, less efficient in terms of time and energy, and less variable (e.g., Weinberg and Hunt, 1976; Beuter and Duda, 1985; Pijpers et al., 2003). In a study examining British soldiers on a stepping task, Collins et al. (2001) found alterations in movement patterns across high- and low-anxiety conditions. Under high anxiety, reductions in movement variability were seen in the rigid coupling of the hip, knee, and ankle joints. Alternatively, performance under low anxiety revealed movements to be less limited and reflecting greater degrees of variability. Pijpers et al. (2003) found similar findings while investigating novice rock climbers. To manipulate anxiety, participants were required to climb at two differing heights (i.e., high and low) on a climbing wall. While climbing high on the wall, participants experienced increased levels of anxiety accompanied by changes in movement behavior. Specifically, movements were longer and less fluent resulting in less efficiency overall. Finally, Beuter and Duda (1985) reported anxiety-related changes in the coordination patterns of children on a stepping task. Under high-anxiety conditions, children produced movements that were less efficient and less smooth when compared to performance under low anxiety. Findings such as these provide a glimpse of the impact performance pressure can have on biomechanical processes.

According to Bernstein (1967) the central task involved with motor learning requires the solving of the degrees of freedom (DOF) problem. The DOF problem is concerned with how the body controls the numerous separate and independent elements (e.g., wrist, elbow, joints, etc.) in the production of coordinated motion. According to Bernstein, and later Vereijken et al. (1992), early learning is typified by an attempt to “freeze” extraneous DOF in order to reduce task complexity. As such, novice motor movements appear rigid, uncoordinated, and stiff. As skill develops through practice, novices begin to “thaw” or release previously frozen DOF resulting in greater independent motion, efficiency, and accuracy (Vickers, 2007). As high-level skill continues to develop, the motor system becomes able to exploit the release of additional DOF making use of the built in mechanical-inertial properties of the limbs (Schmidt and Lee, 1999). As a result, motor performance becomes smoother, faster, and more fluent. However, under pressure, Berstein (1967) postulated that skilled performers may attempt to “refreeze” DOF in an attempt to reduce task complexity and simplify the problem of movement control. As a result, movement execution regresses and parallels earlier stages of skill acquisition (Pijpers et al., 2003). The return to novice “freezing” strategies produces motor movements typified by motions that are rigid and jerky.

Examination of the biomechanical changes associated with anxiety and pressure mirror to a great extent the alterations of the cognitive processes associated with pressure-induced performance failure. In each case, pressure and anxiety appears to return the individual to a
previous lower level of skill functioning (Beilock and Carr, 2001). Cognitive theories of choking under pressure state that performance pressure disrupts automaticity through a return to lower level conscious processing. Biomechanical theories, similarly, propose that pressure and anxiety revert experts back to previous novice “freezing” strategies. These similarities bear witness to the parallels and interactions that each system has with each other.

**Cerebral activity related to perceived pressure and the motor system**

As with the perceptual-cognitive systems, cerebral activity can play a fundamental role in performance under pressure. More specifically, depending on the valence of a stimuli, the lateral nuclei can communicate with the central nucleus in each amygdale, and subsequent connections can travel to critical forebrain, brainstem, autonomic, and endocrine structures that mediate the expression of emotion. Specifically, there are interconnections from the central nuclei to the (1) hypothalamus, which results in sympathetic arousal and stimulation of stress hormones via the hypothalamic-pituitary-adrenal (HPA) axis, (2) the periaqueductal gray, which results in motor responses, and (3) the cingulate cortex, which results in additional cortico-cortical communication with neocortical association regions such as the temporo-parietal regions. Additionally, interconnections to pontine nuclei in the reticular formation result in an increase in overall arousal. In this manner orchestrated sequelae occur in response to a stressful environment, which collectively, can change the performer’s mental and physical state in a profound manner. For example, heart rate and cortisol levels rise, as does muscle tension, and the performer may concomitantly experience excessive self-talk and “too much thinking.” As a result, their attention may become compromised and become explicitly managed, resulting in timing and coordination that is altered and likely reduced in quality.

In support of the “overthinking” hypothesis, Hung et al. (2005) recently provided psychophysiological evidence of increased neural activity between the left temporal region and the motor planning regions of the brain, by assessment of T3-Fz alpha electroencephalogram (EEG) coherence levels, when participants were asked to perform a dart-throwing task under pressure of social evaluation. Relative to a nonstress control condition, the increased neural activity was accompanied by heightened reports of state anxiety and reductions in self-reported confidence levels. As expected, accuracy of performance (i.e., visuomotor coordination) was reduced. However, how these changes were associated with mental representational changes was not studied, but now may contribute to bridging the understanding of covert and overt behaviors.

In light of the mental and physical change alterations that accrue, the activation of the amygdalae serves as a pivotal event in the manifestation of stress. The control of activity in the amygdalae can exert a powerful influence on the performer’s mental and physical state. Beyond the structures and processes outlined by Bear et al. (2001), a critical component of the neurobiology of fear is the executive control over limbic function and subcortical emotional circuits, which is housed anatomically in the frontal regions of the forebrain. Importantly, the anterior cortical regions have extensive anatomical connections with several subcortical limbic structures implicated in emotional behavior, particularly the amygdala (Davidson, 2002, 2004). Davidson and colleagues have generated a significant body of literature that clearly shows a positive association between left frontal activation and positive affect while relative right activation is associated with negative affect (Davidson, 1998; Tomarken et al., 1992). Although the lateralization of frontal activation is robustly related to the valence of emotion, recent evidence points to a more fundamental association such that left frontal activation mediates approach-oriented behavior while right frontal activation is associated with avoidance or withdrawal-oriented behavior (Davidson, 2004). For example, left frontal activation is manifest during hostile behavior, which is certainly not a positive affective state, but most definitely involves approach toward an intended target. Whether positive in nature,
approach oriented, or a combination of the two dimensions, it would appear that such a neuro-biological state would be highly adaptive for the performer who must control his/her emotional level while actively engaged with challenging tasks while under great pressure. How these neural activities are related to perceived pressure, emotions, perceptual, cognitive, and motor systems’ functioning interactively, must be studied within the framework we have outlined.

Conclusion

This chapter introduced a conceptual framework, which links the emotion, cognitive, and motor systems via a mental representation network. This symbolic network is believed to initiate, execute, and control motor actions while interacting with the environment. More specifically, mental representations allow the system to perceive, anticipate, make, and alter decision, and execute actions in the form of neural activity and muscle–joint activation. Under pressure, or any other mental state, impairment in the mental representation network changes either the perceptual, cognitive, or motor systems. These changes must be studied using an integrated method where perceptual, cognitive, and neural activities are studied simultaneously, and both overt and covert behaviors are linked to mental representations, which govern all actions.

References

Defenbacher, J. L. (1978). Worry, emotionality, and task-generated interference in test anxiety: an empirical test of


