CHAPTER 28

Motor Performance

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Skilled motor performance is essential for many activities in daily life, but perhaps more than anywhere else in sport, where optimal performance is often the goal. Skill is characterized by accuracy and consistency in achieving the desired movement outcome, as well as fluent and economical movements that require little physical and mental effort. The role of applied sport scientists, coaches, or physical trainers is to design tasks and practice schedules, provide instruction, and give athletes feedback with the goal of facilitating the learning of effective and efficient movement patterns, and ultimately optimizing performance. Understanding how various factors influence learning and performance is essential for the development of effective training methods.

KEY FACTORS IN LEARNING AND MOTOR PERFORMANCE

In general, an understanding of how the learning process and the performance of motor skills are influenced by practice conditions and instructional methods has significantly evolved. Specifically, three factors have been identified as key for both optimal motor learning and performance. These factors are central to the OPTIMAL (Optimizing Performance Through Intrinsic Motivation and Attention for Learning) theory of motor learning (see figure 28.1; 60). Two of the key variables are motivational, **enhanced expectancies** for performance and **autonomy support**, and one is related to the performers' attention, an **external focus of attention** (see figure 28.1, left). The importance of each factor is supported by extensive lines of research. While learning reflects relatively permanent changes in a person's capability to perform a motor skill as a result of practice, **performance** refers to what is seen, or measured, at any given moment in time (42). Learning studies typically use a **between-subjects design**, including two or more groups of participants who practice under different conditions (e.g., types of feedback or instruction, task order, challenge level), with learning measured by delayed (i.e., 24 hours or more) retention or transfer tests in which all groups perform under the same conditions. The knowledge generated through learning studies can help practitioners design effective practice conditions for longer-term changes in skill. In contrast, studies concerned with motor performance use a **within-subjects design**, where all participants perform under all experimental conditions, typically in a counterbalanced order. Of interest here is how certain factors immediately affect performance. Such studies often have practical implications for enhancing performance, for example, in competitive situations. This chapter reviews findings related to each factor, based on both performance and learning studies, but with particular consideration for those relevant to applied sport scientists. The chapter also provides examples of how sport scientists and coaches may incorporate the three factors in their work with their athletes.

Enhancing Performance Expectancies

Being confident in one's ability to perform well—or having positive expectations for future performance—is critical for optimal motor performance. Providing individuals with a heightened sense of confidence, or enhancing their expectancies, is also important for effective long-term changes in performance (i.e.,

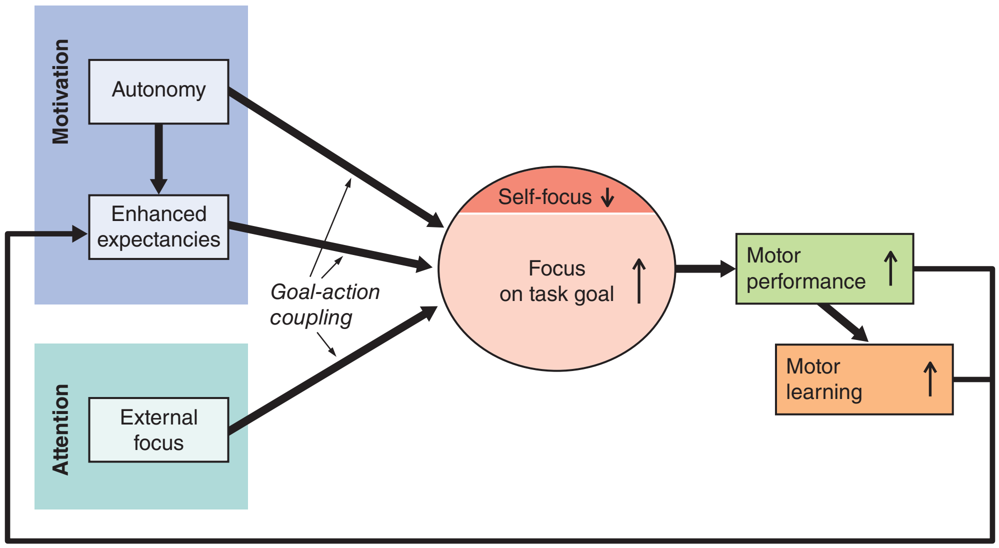

FIGURE 28.1 Schematic of the OPTIMAL theory.

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learning) and sustained performance at a higher level. Experimentally, performance expectancies have been enhanced in various ways. In several studies, feedback was provided to different groups on trials with relatively small errors versus larger errors (3, 5, 41). Intuitively, one might expect feedback to be more effective when it is provided after less successful trials. Yet in several studies, skill learning has been found to be facilitated when feedback is given on more accurate trials. Highlighting good performances increased performers' self-efficacy and therefore resulted in more effective learning than did feedback after poor performance.

Other types of positive feedback have been shown to be effective as well. These include feedback that involves favorable social comparisons. Studies have demonstrated interesting effects when participants were provided with (false) feedback indicating that they were performing above average (although such feedback is not recommended for direct practical application due to its deceptive nature). Relative to participants who received neutral or negative social-comparative feedback, these participants demonstrated enhanced performance and learning of tasks requiring balance, accuracy, sustained maximum force production, or endurance (2, 11, 18). In one such study, the authors used a handgrip dynamometer and found greater sustained maximum force production, increased self-efficacy, and lower perceived exertion as a function of positive normative feedback compared with both negative feedback and control conditions (11). In another study, favorable feedback enhanced running efficiency (i.e., reduced oxygen consumption) in experienced runners (46). Stoate, Wulf, and Lewthwaite asked experienced runners to run on a treadmill, which was set at a speed that corresponded to 75% of their maximal oxygen consumption (46). The authors provided feedback to one group of participants that indicated they were performing more efficiently than others (e.g., "You look very relaxed. You are a very efficient runner."). Oxygen consumption significantly decreased across the run for that group while it remained the same in a control group. Moreover, participants who were given positive feedback reported greater ease of running and increased positive affect. Even maximum aerobic capacity ($\dot{V}O_2$max) has been shown to be increased when runners' expectations were enhanced (28). Participants in that study were experienced runners who completed two $\dot{V}O_2$max tests within 2 weeks. Before the second test, the experimenter made a casual remark to one group of participants, letting them know that their aerobic capacity on the first test was above the group average. Providing runners with this positive feedback resulted in a significant increase in $\dot{V}O_2$max (+3.28%) relative to their first test. The other group (control) showed a decrease in $\dot{V}O_2$max, presumably because participants were disinclined to run to exhaustion again within a relatively short period of time. Thus, even though maximal oxygen consumption is typically assumed to be an objective and reliable measure of physical fitness, findings showed that even maximal aerobic capacity can vary as a function of the individual's self-efficacy expectations.

Other studies have also demonstrated that simple statements can suffice to promote performance and learning. Information suggesting that peers typically do well on a given task or encouraging statements about the learner's performance or improvement resulted in more effective learning than no such information (54, 55). Increasing performers' perceptions of success can be achieved through other means as well. For example, setting criteria that purportedly indicate good performance, but that can be reached relatively easily, will raise learners' expectancies—with beneficial effects for performance and learning (31, 47, 67). In one study, participants performed a golf putting task in which the target was surrounded by two concentric circles (31). One group was informed that putting within the larger circle would constitute good putts, whereas another group was told that balls ending up in the smaller circles would be considered good. While one might expect the smaller circle to lead to more intense concentration and enhanced learning, the large-circle group actually putted more accurately during the practice phase than did the other group (small circle). Importantly, in delayed retention and transfer tests, with the circles removed, these group differences were maintained. Thus, making learners feel successful during practice resulted in more effective learning (47).

A study of professional golfers on the European Professional Golfers' Association tour highlights the importance of expectancies for performance (40). The authors examined performance in subsequent tournaments 1 week after a golfer barely made or missed the prior tournament's cut. Uninfluenced by preexisting skill differences (scoring average), those golfers who had received a boost of confidence from making the cut outperformed those who just failed to make the cut in the next tournament.

Autonomy

Performer autonomy is another variable that appears to be indispensable for optimal performance and learning. Conditions that give performers a sense of autonomy, for example, by providing them with choices, are beneficial for motor performance and learning. For instance, allowing learners to choose when to receive feedback about their performance (15), letting them decide when to use an assistive device (4), or letting them choose the amount of practice (38) has been shown to enhance learning.

The motivational underpinnings of the learner-controlled practice were first highlighted by Lewthwaite and Wulf (19). Interestingly, and in line with this view, even minor and seemingly insignificant choices have been found to facilitate learning and performance. For example, in one study (51), participants were asked to perform three different balance exercises. In one group, participants were able to choose the order in which they wanted to perform those tasks. In the control group, the order was chosen for them. In fact, each participant's order was determined, unbeknownst to them, by what an assigned counterpart in the choice group had selected. The choice group showed superior balance performance on all tasks, compared with the control group, throughout the practice phase. More importantly, a delayed retention test with a fixed order of tasks demonstrated that this minor choice also enhanced learning. In another study, using different exercises (lunges, jumping jacks, bear crawls, medicine ball throws) but a similar experimental design, participants were also able to choose the order of exercises (choice group) or not (control group) (58). Before performing the tasks, all participants were asked how many sets and repetitions they wanted to complete for each exercise. Participants in the choice group chose to perform a significantly greater number of sets (3.0) and repetitions (13.2), on average, than did the control group participants (2.3 sets, 10.8 repetitions). Autonomy-supportive climates have been found to be associated with persistence in activity engagement in other studies as well (61, 64). Thus, an additional benefit of giving learners choices is that it can increase their motivation to practice—which might have additional indirect benefits for learning.

Choices as trivial as the color of objects or equipment to be used have been shown to lead to more effective motor learning. This includes one study (17) in which participants were able to choose the color of golf balls on a putting task. Specifically, in a choice group, learners had the opportunity to choose the ball color (white, orange, or yellow) six times during the practice phase. In the control group, learners were provided balls of the same color that an assigned counterpart in the choice group had used. The choice group demonstrated superior learning, as measured by putting accuracy on a retention test 1 day later, in which only white balls were used.

To see "how low one can go," Lewthwaite and colleagues conducted another experiment in which they gave one group of learners choices that were completely unrelated to the task they were about to learn (i.e., a balance task) (17). Participants were given a choice related to a different task they would practice afterward, and they were asked their opinion as to which of two pictures should be hung on the laboratory wall. Relative to a control group that was simply informed of the second task or the picture to be hung, the choice group demonstrated more effective learning of the balance task. These findings demonstrate that giving learners choices—even small ones or ones that are incidental to the task—have the capacity to facilitate motor skill learning.

Furthermore, the type of instructional language has been found to have an impact on motor learning. Hooyman and colleagues (10) varied the way in which instructions for performing a novel motor task, a cricket bowling action, were presented. Instructions that gave the learners a sense of choice (autonomy-supportive language) led to superior learning than instructions that offered little option for how to execute the skill (controlling language). On a delayed retention test without further instructions, the autonomy-supportive language group showed greater accuracy in hitting a target than did the controlling-language group.

Providing individuals choices has also been shown to have benefits for maximum force production and movement efficiency. For instance, in a study by Halperin and coworkers (9), kickboxers who competed at national and international levels performed standard punching performance tests across several days. Each test consisted of maximal-effort punches completed in a specific order: lead straight, rear straight, lead hook, and rear hook. This standard protocol served as the control condition. Each athlete also performed an additional test under a choice condition on each day. That is, the athlete delivered the same number and types of punches but was able to choose the order of those punches. The choice (A) and control (B) conditions were completed in a counterbalanced order across 6 days (AB-BA-AB-BA-AB-BA). Allowing the boxers to choose the order of punches generally led to greater punching velocity and higher impact forces than did an assigned order of punches. A relatively small choice resulted in athletes' punching faster and harder, even though they were highly skilled athletes who had extensive experience with the task. In a follow-up study with non-athletes, Iwatsuki and colleagues (12) asked participants to squeeze a hand dynamometer and perform several repeated maximum-effort trials. When participants were able to choose the order of their right and left hands, they were able to maintain maximum forces. In contrast, forces declined in control group participants (each of whom had the same order of hands as an assigned counterpart in the choice group). Thus, an increased sense of autonomy seemed to facilitate sustained maximal force production.

The production of maximum forces requires optimal motor unit recruitment as well as avoidance of unnecessary cocontractions of muscles. The studies by Halperin and colleagues (9) and Iwatsuki and colleagues (12) provided initial evidence that autonomy support may indeed facilitate neurophysiological efficiency. More direct evidence for this notion was sought in a study by Iwatsuki and colleagues (13). In their study, participants completed a 20-minute submaximal run (65% of $\dot{V}O_2max$) on a treadmill. Before the run, participants in one group were able to choose pictures that would be shown to them on a screen during the run. Throughout the run, this group ran with greater efficiency, as measured by oxygen consumption and heart rate, compared with performers viewing the same picture but without having a choice.

The most direct evidence for increased movement efficiency resulting from autonomy support comes from a study by Iwatsuki and colleagues (14) in which they examined the effects of performer autonomy on motor performance by measuring neuromuscular activity through the use of electromyography (EMG). Participants were asked to perform a motor task that involved the production of accurate forces through ankle plantar flexion. All participants performed three variations of the task (i.e., different target torques: 80%, 50%, 20% of maximum voluntary contractions) under both choice and control conditions. The results showed that EMG activity was lower in the choice relative to the control condition. That is, participants produced the same torques with less muscle activation when they had a small choice (task order). These findings highlight the importance of autonomy support for neuromuscular efficiency.

External Focus of Attention

A performer's focus of attention plays another key role with respect to the effectiveness and efficiency of movements. Since about the turn of the century, many studies have shown that adopting an external focus, that is, concentrating on the intended movement effect, enhances motor performance and learning compared with an internal focus on body movements

(59). An external focus might be one that is directed at the motion of an implement (e.g., racquet, ball, skis, discus, kayak), even a sticker attached to the body (e.g., chest), a target to be hit, the force exerted against the ground, or an image such as the pendulum-like motion of a golf club. Compared with an internal focus (e.g., arms, shoulders, hips), an external focus enhances movement effectiveness (e.g., movement accuracy) and efficiency (e.g., muscle activation). This benefit to performance and learning has been demonstrated for a wide variety of skills, levels of expertise, age, or ability or disability. In essence, by adopting an external focus, a higher skill level is reached in less time (for reviews, see Wulf (50) and Wulf and Lewthwaite (60)).

This section highlights some findings related to the efficiency of movements as a function of an external versus internal focus. A movement pattern is considered more efficient or economical if the same movement outcome is achieved with less energy expended. Direct measures of efficiency include muscular (EMG) activity, oxygen consumption, and heart rate. Neuromuscular efficiency is also reflected in the production of forces and can therefore be seen in maximum force production, movement speed, or muscular endurance.

Several studies measured EMG activity in participants who performed motor tasks under external versus internal focus conditions. In the first study, by Vance and colleagues (48), participants performed biceps curls while concentrating on the weight bar (external focus) or their arms (internal focus). An external focus resulted in lower EMG activity in both agonist and antagonist muscles (see also Marchant and colleagues (24)). Greater efficiency with an external focus has also been found in studies involving an isometric force production task (22). The participants' task was to press against a force platform with their foot with 30% of their maximum force. Focusing on the calf muscles (internal) led to less accurate force production than did concentrating on the force platform (external), as well as higher degrees of muscle activation and increased cocontractions between agonists and antagonists. The authors also found indications of superfluous motor unit recruitment of larger motor units within the muscles when participants focused internally. Unnecessary muscle activation—be it between muscles or within muscles—interferes with movement accuracy. Therefore, in target-oriented tasks such as basketball free throws (65) and dart throwing (21), higher degrees of muscle activation with an internal focus were associated with reduced accuracy. In contrast, an external focus on the hoop or dart trajectory, respectively, resulted in greater accuracy and lower activation of arm muscles.

Reduced muscular activity with an external relative to an internal focus is associated not only with more accurate force production, but also with the production of greater maximal forces. The production of maximum force requires an optimal activation of agonist and antagonist muscles, as well as optimal muscle fiber recruitment. Cocontractions, imperfect timing, or direction of forces (or more than one of these) would result in less than maximal force output. Marchant and colleagues (25) asked experienced exercisers to produce maximum voluntary isokinetic contractions of the elbow flexors while focusing on their arm muscles (internal) or the crank bar of the dynamometer (external). Participants produced significantly greater peak joint torque when they focused externally.

Maximum vertical jump height has also been also found to be increased with an external relative to an internal focus (and control conditions) (56, 63). Participants in those studies were instructed to concentrate on the tips of their fingers (internal) or on the rungs (external) of the measurement device (e.g., a Vertec) they attempted to displace during the jumps. Performers jumped significantly higher with the external focus. Furthermore, the vertical displacements of the center of mass, impulses, and joint moments about the ankle, knee, and hip joints were significantly greater—demonstrating that increased jump height with an external focus was achieved through greater force production (56). Moreover, greater jump height with an external focus was associated with reduced EMG activity, indicating increased neuromuscular efficiency (57). Standing long-jump performance has also been shown to be enhanced with an external focus (33, 35, 49). Also, the performance of other skills requiring maximum force production, such as discus throwing (66), has been shown to benefit from an external focus.

The greater efficiency with an external focus also manifests itself in increased movement fluidity, speed, and endurance. Porter and colleagues demonstrated the benefits of adopting an external focus for tasks involving running (34, 36). In one study, the authors found that an external focus reduced the time taken to complete a whole-body agility task (e.g., an L run) (34). Relative to internal focus instructions and control conditions, the same participants ran faster when given external focus instructions. In another study (36), 20-meter sprint times were significantly reduced with an external focus (i.e., clawing the floor with the shoes) compared with an internal focus (i.e., moving the legs and feet down and back as quickly as possible). Focus of attention also affects swim speed. Both intermediate swimmers (7) and expert swimmers (45) were found to swim faster when they were asked to focus on pushing the water back (external focus) relative to pulling their hands back (internal focus).

Greater neuromuscular efficiency with an external focus should also manifest itself in increased endurance since greater efficiency means less energy is consumed. In one study (43), oxygen consumption as a function of attentional focus was measured in skilled runners. For three 10-minute periods, they ran on a treadmill at a speed that corresponded to 75% of their $\dot{V}O_2max$ under the respective focus conditions. For 10 minutes each, they were asked to concentrate on their running movement (internal focus), breathing (internal focus), or a video display that simulated running outdoors (external focus). The results showed that runners needed significantly less oxygen with an external focus of attention compared with either of the internal foci.

Another study examined muscular endurance in trained individuals performing exercise routines (23). The authors measured the number of repetitions to failure during various exercises (i.e., assisted bench press, free bench press, free squat lift) with weights corresponding to 75% of each participant's repetition maximum. An external focus on the movement of the bar being lifted allowed for a significantly greater number of repetitions than an internal focus on the movements of the limbs involved (i.e., arms, legs) in all three exercises. In another study using an isometric force production task (e.g., a wall sit), Lohse and Sherwood (20) found increased time to failure with external focus (keeping imaginary lines between the hips and knees horizontal) versus internal focus (horizontal position of the thighs). Thus, there is converging evidence demonstrating greater movement efficiency when performers adopt an external focus of attention.

KEY MOTOR PERFORMANCE FACTORS AND PERFORMANCE OPTIMIZATION

High expectancies prepare the performer for movement success at various levels (e.g., cognitive, attentional, neuromuscular). They ensure that movement goals are effectively coupled with necessary actions. **Goal-action coupling** (see figure 28.1) refers to the fluidity with which the intended movement goal is translated into action (60). An important feature of goal-action coupling is effective and efficient neuromuscular coordination (e.g., recruitment of motor units). Confidence protects the performer from thoughts that would interfere with optimal performance, such as distracting thoughts or self-referential thinking (26) that reduces attentional capacity and detracts from a goal focus. As indicated in figure 28.1, high performance expectancies have a dual role for goal-action coupling: maintaining a focus on the task goal and preventing a self-focus (or other distracting thoughts). Expectations of rewarding experiences elicit dopaminergic responses (44) that facilitate the establishment of functional neural connections necessary for successful motor performance. Dopamine, in conjunction with task practice, also facilitates the consolidation of memories (i.e., learning) and builds structural and functional connections that underlie skilled performance (e.g., Milton and colleagues (27)).

Autonomy-supportive conditions are rewarding (30) and thus increase individuals' anticipation or expectations for future reward or success. Thus, they enhance performance and learning through the enhanced expectancy route. Autonomy, or lack thereof, may also have a more direct impact on motor performance and learning (see arrow from autonomy to self-focus or focus on task goal in figure 28.1). Controlling conditions that deprive performers of a sense of autonomy tend to be stressful (39). The stress hormone cortisol has a downregulatory effect on the brain's reward network (29), which might contribute to degraded learning under those conditions (10). Autonomy-supportive conditions allow performers to focus their attention (externally) on the task goal, without the need for self-regulatory activity resulting from controlling environments.

An external focus directly contributes to goal-action coupling by helping the performer direct attention to the task goal and preventing disruptive body or self-related distractions from the task goal. That is, an external focus is assumed to facilitate neural connections that are critical for optimal performance. The result is greater automaticity (62) and neural efficiency (16) (for a review, see Wulf (50)). In addition, by consistently producing successful movement outcomes, an external focus likely enhances expectancies for future performance and goal-action coupling (see figure 18.1).

IMPLICATIONS FOR APPLIED SPORT SCIENCE

The findings reviewed in this chapter have important practical implications. This final section summarizes the main points made throughout this chapter and gives examples of how sport scientists might apply these principles. Table 28.1 provides an overview of the key factors for optimal performance, different means of implementation, and specific examples.

Enhancing Athletes' Performance Expectancies

Sport scientists can facilitate movement effectiveness and efficiency relatively easily by enhancing their athletes' performance expectancies. The ability to sustain effort, the ability to move efficiently and accurately, and the ability to maintain balance are all key attributes of successful performance. To this end, coaches may want to reconsider a number of factors that are considered standard practice in coaching. These include the predominance of offering feedback on unsuccessful trials instead of successful ones. Feedback that is mostly corrective or prescriptive (or both) tends to undermine the performer's confidence, with negative consequences for performance. In contrast, performance and learning benefit when performers feel competent and successful. Furthermore, setting performance goals that are challenging but achievable can serve to provide athletes with a boost of confidence, which in turn will enhance their motivation, performance, and learning. Enhanced performance expectancies are also important during warm-up before a competition. Setting simple and attainable goals during the warm-up, or ending the warm-up with a successful trial, can help athletes enhance their expectancies for performance in the upcoming competition.

Providing Autonomy Support

The effects of autonomy support also have considerable implications for athletes and coaches. The findings reported here seem to contrast with approaches that are predominant in applied settings. Coaches often program the task they want athletes to perform, or the order of different tasks, and they provide feedback or give demonstrations of the skill when they believe it is necessary or helpful. Sport scientists can help their athletes move more effectively and efficiently by providing them with choices. Even small or incidental choices have been shown to result in more effective performance and learning, enhanced motivation, and positive affect. Instructional language that is autonomy-supportive rather than controlling has similar effects. Potential benefits include (competitive) performance advantages, experiences of movement fluidity and effortlessness, and longer practice durations.

TABLE 28.1 Key Factors for Optimal Performance and Learning

Key factors for optimal performance and learning	Ways of implementation	Examples
Enhanced expectancies	• Positive outcome expectations • Positive feedback, including after good trials • Liberal definitions of success • Task difficulty that allows for success with challenge • Proximal, measurable goals	Highlighting an athlete's improvement or providing feedback about positive aspects of performance
Autonomy	• Self-controlled feedback, assistive devices, amount of practice, and so on • Small and incidental choices • Autonomy-supportive instructions	Allowing an athlete to choose the order of exercises or the number of repetitions
External focus of attention	Instructions or feedback that directs concentration to the intended movement effect: • Implement (e.g., golf club, discus, skis, weights) • Environment (e.g., water, ground, target) • Images, analogies, metaphors	Giving instructions that direct the athlete's attention to the desired spin of a ball or the motion of a weight bar

Promoting an External Focus

Because of the consistency with which an external focus has been shown to facilitate performance and learning, it should be considered the default attentional focus. Subtle differences in the wording of instructions or feedback can have a significant impact on immediate performance and longer-term learning. Yet even experienced performers do not always adopt the optimal focus, which may be partly the result of histories of instruction (8). For example, in interviews with track and field competitors at national championships, the majority (84.6%) reported that their coaches gave instructions related to body movements (37). Instructors, coaches, and performers themselves should be aware of the strength of the evidence favoring an external focus and should develop strategies to identify and maintain external foci. These efforts may require creativity and experimentation in finding the right external focus, as well as include changes to those foci as the performer's skill level increases. The benefits for performance and learning are arguably among the most reliable with regard to supporting effective performance.

Additive Benefits

Practitioners might wonder whether it is necessary to include all three factors (enhanced expectancies, autonomy, external focus) in practice or training protocols. The importance of each factor for enhancing performance and learning has been demonstrated in numerous studies. While each of these variables plays an important role in and of itself, a series of studies has shown that these factors can have additive benefits. Conditions that included combinations of two factors resulted in greater benefits than did those that included only one of these factors, or none (1, 32, 52, 53). Moreover, the presence of all three factors enhanced learning to an even greater extent than did combinations of two factors (61). One study addressed for the first time the question whether motor performance could be immediately enhanced by implementing all three factors in succession (6). Using a maximum vertical jump test, the authors indeed found additive benefits for performance. With each addition of a variable on successive blocks of trials in one group, jump height increased whereas it did not change in a control group. Thus, "maximum" jump height was further enhanced by each variable.

Performance Testing

These findings also have implications for performance testing. The fact that simple conditions promoting enhanced expectancies, performer autonomy, and an external focus of attention can enhance performance suggests that performance under neutral conditions does not necessarily represent the individual's optimal or maximal performance. That is, what is seen, even with maximal-effort instructions, is not necessarily all that can be produced. Using optimized performance conditions can help testers ensure that their measurements for a maximum neurophysiological or cardiovascular assessment are as close as possible to maximal performance when that is the desired outcome. Practitioners should be aware of these influences in their work when assessing athletes' capabilities.

CONCLUSION

Sport scientists can easily take advantage of the effects outlined in this chapter. These require little more than small changes in the way instructions or feedback is given—and, of course, some creativity. Giving their athletes choices, providing success experiences, and avoiding references to body movements and instead directing their attention externally can go a long way in terms of facilitating motor performance and learning. The resulting movement success may even create a "virtuous cycle" with overall positive consequences for learning, performance, and motivation.

RECOMMENDED READINGS

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