Challenge Point Framework and Efficient Learning of Golf

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ABSTRACT
The current paper overviews a framework for motor learning and uses this framework to suggest efficient means to practice golf. The framework, known as the Challenge Point Framework, was built from years of laboratory and field studies that have been shown to enhance learning. Throughout the paper, the relationship between practice protocols and the learning that results from them are discussed and where appropriate golf-related examples are provided for the reader to be able to translate from motor learning and neuroscience research to the application of golf. Ultimately, the aim of the article is to show how the Challenge Point Framework can be used to enhance golf performance.

Key words: Contextual Interference, Feedback, Motor Learning, Practice, Task Difficulty

INTRODUCTION

PRACTICE/RETENTION PARADOX

Over the years, a great deal of debate has existed over the most appropriate practice schedule for efficient learning. This debate takes place in laboratory settings and in the field, and spans several practice questions such as how much variability in practice is best, and what is the appropriate amount of feedback. Although these questions may not appear to have a great deal in common, one finding is shared across the answers: In studies of feedback and practice organization, practice performance is not necessarily indicative of learning (i.e., retention performance). In golf, for example, this can be translated to suggest that how a player performs on the range does not predict how well the player will play on the course. In fact, it has been repeatedly shown that when using certain common practice methods, the group that

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performs best during practice performs worst during the test. If this was always the case, the equation would be simple: Practice methods that promote good practice performance create poor test/competition performance. Therefore, based on this equation, one could conclude that the best practice for enhancing performance would be one in which the individual performs the worst. However, the equation is not quite that simple. Indeed, a variety of practice and retention relationships have been demonstrated including good practice and good retention [1], poor practice and good retention [2], and poor practice and poor retention [3]. Perhaps the simplest way to state the relationship between practice and learning (retention) is that it is paradoxical. Under certain circumstances, they relate to each other in a direct manner (if one is good, the other is good) and in other circumstances they relate to each other in a reciprocal manner (if one is good, the other is bad). Therefore, one would presume that a rather complex formula between practice and retention is necessary to describe the relationship. Fortunately, it has been suggested that this relationship need not be so complicated [4, 5, 6]. The principle proposed by Guadagnoli & Lee [4] and presented in this article describes the relationship between practice method and competition performance in a straightforward, simple manner. Specifically, the Challenge Point Framework [4] is presented here and adapted specifically for the efficient learning of golf.

To better understand the specifics of the Challenge Point Framework, it is necessary to understand the research that supports it. Additionally, this research provides important clues as to the most effective means of practice to facilitate learning for each level of expertise in golf.

REVIEW OF LITERATURE

CONTEXTUAL INTERFERENCE

The term contextual interference was introduced by Battig [7] to describe the interference that results from practicing a variety of tasks within the context of a single practice situation (see [8] for a review). A low degree of contextual interference can be established by having the performer practice only one task within a block of trials (i.e., blocked practice). For example, attempting the same four-foot putt time after time would constitute low contextual interference. A high degree of contextual interference can be established by having the performer practice several tasks in a random order (i.e., random practice). For example, attempting to putt from a different position four feet away from the pin each time would constitute high contextual interference relative to practicing from the same position on a repetitive basis. A series of studies using a blocked/random manipulation, demonstrated that low contextual interference practice (relative to high contextual interference practice) led to a practice/retention paradox. The individuals who practice skills in a blocked fashion performed better than the individuals who practiced in a random fashion. Interestingly, when they were tested later, the opposite effect was demonstrated: the random group performed better on the test than the blocked group [2, 9].

The practice/retention paradox seen in the Shea studies [2, 9] is not always the rule. Rather, it appears that the paradox is related to the complexity of the task and the skill level of the performer. In fact, it has been demonstrated that for inexperienced individuals, high levels of contextual interference during practice can be less beneficial for learning relative to low levels of interference [10, 11]. More specifically related to golf, Guadagnoli et al. [12] investigated blocked and random practice with two different levels of performer (Novice or Experienced) for the task of putting. During practice, novice and experienced golfers practiced under a blocked or random schedule. As in previous contextual interference studies, subjects who practiced under a blocked schedule performed better than those who practiced under a random schedule, and this was regardless of experience level. Intuitively this makes sense, because practicing the same putt in a repetitive fashion is 'easier' then changing the putt each time. Indeed, repetitive putting is commonly used in real world practice. However, more important than practice success is retention success or learning. During the retention test of Guadagnoli et al. [12], novice subjects who practiced under a blocked protocol performed better than novice subjects who practiced under a random protocol. The opposite was true for experienced subjects: Experienced subjects who practiced under a random protocol performed better than experienced subjects who practiced under a blocked protocol. Presumably, blocked practice provided the most appropriate challenge for novice golfers and random practice provided the most appropriate challenge for experienced golfers. From these results, it was concluded that for novice performers, decreasing extraneous challenge is desired, but as the performer becomes more proficient, more challenge is desired. More important to the present paper is the fact that the Guadagnoli et al. [12] study clearly demonstrated that efficient learning is based on challenging the performer appropriately, and this means different practice for different levels of ability. For example, efficient practice for a novice golfer may be practicing the same putt 3-5 times in a row. This same practice method may benefit experienced golfers during practice, but is unlikely to cause learning. For the experienced golfer an appropriate practice method may be practicing a putt 1-2 times before changing distance and/direction of the putt. Further, it is reasonable to extrapolate this logic to the full swing as well. That is, on the driving range novice golfers may want to use the same club for 5-6 shots in a row whereas experienced golfers change clubs every 2-3 shots. As is stated later in the paper, the specifics of the interference practice protocol depend on the expertise of the individual and the complexity of the task.

Recent evidence in neuroscience may provide insight into why various levels of challenge affect people differently. During exposure to challenging or stressful situations such as a random practice schedule, one of the earliest signals of stress is the presence of a hormone known as corticotrophin-releasing factor (CRF). In the case of the current paper, stress is a physiological response to mental or physical factors. By its nature, random practice is considered more difficult than blocked practice (based on performance data) and therefore more stressful. CRF hormone is released in the hippocampus, a brain structure central to learning and memory [13]. It appears that CRF impacts our ability to remember performance information [14, 15]. The nature of this impact is highly dependent on the difficulty of the practice situation. Specifically, under moderately stressful learning situations increased levels of CRF have been found to increase skill learning [16]. The defining phrase here is "under moderately stressful learning situations." What is or is not moderately stressful is largely dependent on the individual performing the skill. Excluding personality differences, we can generally say that how one perceives difficulty is based on their skill level. Putting repetitively to a hole four feet away may be perceived as moderately difficulty to the novice golfer, but easy to the experienced golfer. The key seems to be creating a practice schedule that creates appropriate stress for the performer, thus setting the stage for faster, more efficient skill acquisition.

When considering these behavioral observations in light of recent neuroanatomical findings, the reason for increased learning for experts in random practice situations becomes even clearer. As an individual learns a motor skill, the different areas of the brain are preferentially recruited for performance of that skill [17, 18]. In the expert performer, remodeling of the motor cortex has created a stable neural circuit in which the performance of the skill takes place [19]. Neural circuit is defined here as a cluster of neurons associated with a particular movement sequence. In the random practice situation, the stability of the performance circuit might be interfered with, essentially redirecting the expert performer's attention to task performance. This attention, in turn, enables the performer to recruit the areas of the brain used in initial skill acquisition for skill remodeling [20]. In essence, random practice both increases the stress response in the expert performer to optimal levels by creating an appropriate release of CRF in the memory areas in the brain and enables re-activation of the areas involved in initial task learning. As noted in the onset of this paper, contextual interference is not the only way to create appropriately stressful practice situations.

KNOWLEDGE OF RESULTS

A generally accepted principle in motor learning is that feedback describing a performer's success is a critically important factor in performance and learning [21, 22, 23]. Understandably then, the relationship between feedback and the learning of motor skills has for some time been a source of interest for practitioners and theorists alike. Experimentally, this relationship has been studied chiefly via knowledge of results (KR), commonly defined as augmented, post-response, error information. In the past few decades, the scheduling of KR has been investigated under a variety of conditions [21, 23, 24, 25]. One such variation of scheduling KR that has drawn attention over the years is known as summary KR [26, 27].

Summary Knowledge of Results

Summary KR is augmented error information given to an individual after he/she has completed a series of trials. For example, summary-5 means that the individual completes five trials before receiving KR about those trials. This would be the equivalent of a golfer hitting five shots on the range before getting feedback from the instructor about those five shots. Findings from summary KR experiments, like contextual interference experiments, have demonstrated the practice/learning paradox. Specifically, this feedback method has been shown to hinder practice performance while benefiting learning [3, 26, 27]. This fact was first introduced into motor learning research by Lavery [26], the results of which contradicted both intuition and traditional views of learning that suggested that any variation of KR that provides more precise, frequent, and/or accurate information on movement outcome has a positive affect on learning. A number of researchers have suggested that if KR is given to the performer immediately after a response, the performer is not motivated to process other information (e.g., internal feedback) that may be useful for skill practice [22, 24, 25, 26, 28]. Rather, the performer uses the KR to guide trial-to-trial performance instead of actually learning to solve the motor problem [23]. By combining the motor behavior research with current neuroscience research one might logically infer that withholding feedback for several trials is a potential stressor to the performer. The extent to which it is stressful depends on the level of the performer and the complexity of the task. This concept has been demonstrated in two notable motor learning studies.

Schmidt, Lange and Young [29] predicted that optimal length of summary KR was task dependent. That is, for an individual to successfully complete a task of greater complexity, more augmented resources would be necessary than for the same individual to solve a task of less complexity. This suggests that if an individual is to learn a complex task, more immediate KR should be given relative to the same individual learning a simple task. In fact, Schmidt et al.'s [29] prediction was correct. With a relatively complex task, a medium summary length was most effective for learning, relative to the short and long summary lengths. This information is an integral part of the Challenge Point Framework that we will discuss later in this paper. The implication of this work is that optimal KR can be used to enhance the learning of a golf swing.

In a more recent paper, Guadagnoli et al. [3] suggested that in addition to being task dependent, optimal summary length is performer dependent. In the first of two experiments, it was found that as a learner practices more, the optimal summary KR length increases. That is, inexperienced individuals perform better during both practice and retention if given a shorter summary KR length than if given a longer summary KR length. As subjects received more practice, the shorter summary continued to produce better performance during practice but produced poorer retention performance relative to a longer summary KR length. Therefore, when task difficulty is held constant over practice trials, longer summary length KR yields superior retention performance for the experienced individual and inferior performance for the novice.

In their second experiment, Guadagnoli et al. [3] tested the extent to which optimal summary length is affected by task-related experience and complexity. For example, is it best to give novice golfers immediate feedback or delayed feedback, and how does this change as experience level changes? The answer is clearly that optimal KR is performer and task dependent. It was found that experienced subjects practicing a complex task performed with similar accuracy as inexperienced subjects practicing a simple task. That is, the relative difficulty of the motor problem for an experienced person performing a difficult task paralleled that of an inexperienced person performing a simple task. In contrast, the relative difficulty for an experienced person performing a simple task is opposite that of an inexperienced person performing a difficult task. It was concluded that the relative difficulty of the motor problem is contingent on both the complexity of the task and the performer's experience. As such, it may be suggested that a relatively short summary is most appropriate for a novice golfer or a golfer learning a relatively complicated task (e.g., cut swing). For example, if the task to be learned is relatively complex, feedback should be given every 2-3 trials. However, if the task is less complex feedback should be given every

7-10 trials. Again, the important point here is that practice is made sufficiently challenging for the learner and feedback presentation is yet another way to alter challenge.

If the behavioral findings on summary KR are viewed in light of the stress response literature, the finding that the most beneficial learning occurs at medium summary KR length becomes intuitive. Reliance on external feedback to interpret performance success, as is seen in the short summary KR condition, creates very little stress response and an internal situation in which CRF is not released [13]. On the other hand, long summary length KR may result in a situation where there is an overabundance of stress in the system related to the attempt to interpret and integrate sensory information from multiple sources. In the medium length summary KR situation, the learner is receiving spacing between KR trials such that some stress response is induced, therefore CRF is released, but not so much stress that learning is inhibited.

Taken together, the literature above suggests three important points:

- Practice performance is not necessarily indicative of learning as shown through the practice/retention paradox.
- The relative difficulty of a task is dependent on both the complexity of the task and the level of the performer.
- As the level of the performer increases the challenge of the practice protocol should increase, thus maintaining relative task difficulty.

THEORY BASE FOR THE PARADOX PRINCIPLE

A global explanation of the cited findings is largely based on Miller's [30] classic account of information capacity limitations, and Newell and Rosenbloom's [31] explanation of motor learning performance curves based on a chunking model. A basic premise of chunking models is that one's ability to process and store information is of fixed capacity. Learning then, results from increasing the system's efficiency rather than expanding the capacity. As a function of increased practice, task elements can be grouped together in memory into larger and larger units. As a result, the number of steps to process the same number of task elements decreases; hence, information processing activities become more efficient. As this happens, the same task becomes easier or less stressful, which in turn determines appropriate practice for efficient learning.

When the performer is in an early stage of learning, the system is inefficient in grouping multiple task elements. Therefore, the information needs to be presented in smaller units for efficient processing. Situations such as a shorter summary KR length or less practice variability provide information in smaller and/or more suitably organized units. Therefore, these schedules lead to more efficient learning for an early stage learner. Likewise, when a performer is in a later stage of learning, the system's ability to group information improves and thus the individual can more efficiently handle a more demanding practice protocol. The overall efficiency of processing information is dependent on the relative difficulty of the task. Therefore, task difficulty is based on the level of the performer and the specific constraints of the task itself.

When one learns, the dynamics of the system have to change to increase its efficiency because the system's constraints do not change. We interpret the studies reviewed thus far to have demonstrated an optimal relationship between practice protocol and relative task difficulty by producing the conditions necessary to manifest a learning phenomenon within the confines of the system's constraints. These confines seem to be highly sensitive to relative task difficulty and therefore the influences of practice (i.e., the level of the performer). Hence, the review provides insight into the dynamics of the system and how these dynamics change as a function of the level of the performer and therefore provide a basis for a principle of motor learning.

THE CHALLENGE POINT FRAMEWORK FOR MOTOR LEARNING

Guadagnoli and Lee [4] proposed a Challenge Point Framework for motor learning. The Challenge Point Framework suggests that learning is optimal when the performer is appropriately challenged. This paper adapts the Challenge Point Framework specifically to the sport of golf.

Figure 1 is a simple graphic of the hypothetical relationship between practice performance and task difficulty. For the current paper, task difficulty is defined as the amount of stress that results from the need to resolve a particular motor problem. This stress can result from one's perception (e.g., psychological factors) of task difficulty and/or the mechanical constraints (e.g., degrees of freedom) of the task. For example,

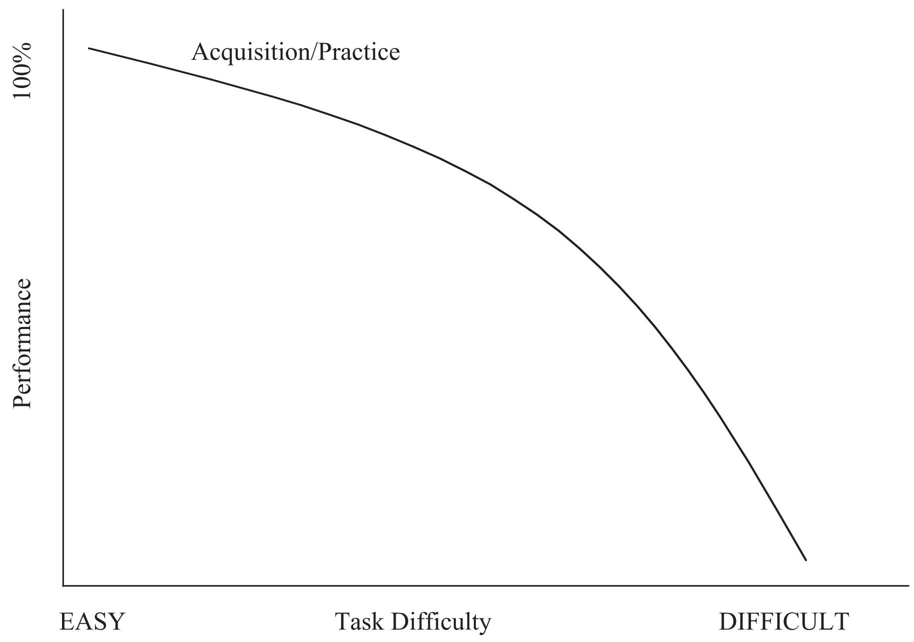

Figure 1. The Hypothetical Relationship Between Practice Performance and Task Difficulty

making a 2-foot putt is generally less difficult (i.e., stressful) than making a 30-foot putt or driving the ball into a fairway that is 20-yards wide. As noted above, practice task difficulty has been manipulated through changes in task complexity, frequency and/or scheduling of KR, practice organization, experience level, etc. As shown in Figure 1, practice performance decreases as task difficulty increases. That is, as the motor problem becomes more difficult, immediate performance deteriorates. It is obvious that practice performance decreases as task difficulty increases. On the driving range, changing clubs each shot makes practice more difficult than hitting the same club time after time. As a result, practice performance may suffer from changing clubs each shot on the range. However, most people who play golf are more interested in how they perform on the course than on the range and therefore the true test of success on the range is how they play on the course. Using the language of the Challenge Point, practice performance is less important than retention performance or learning.

Figure 2 extends the relationship between performance and task difficulty to include learning and task difficulty. Again, we see practice performance decrease as task difficulty increases. From the first half of the graph, however, we can see that learning increases as task difficulty increases. This increased learning continues until the optimal challenge point (OCP) is reached. At this point, the learner is being optimally challenged and efficient learning can occur. Therefore, as task difficulty increases from relatively easy to the OCP, practice performance decreases but learning is enhanced. That is, as stress is increased, immediate performance is

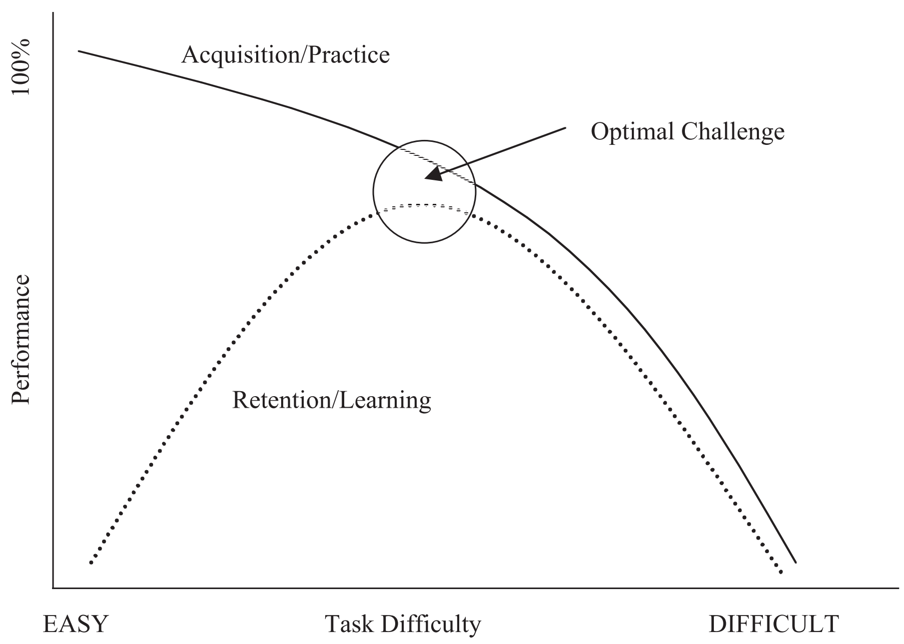

Figure 2. The Hypothetical Relationship Between Practice Performance and Retention Performance for Differing Levels of Task Difficulty

negatively affected but the long-term benefits of practice are enhanced. However, if stress is increased beyond the OCP, both practice performance and learning begin to suffer. This finding is consistent with the findings from neuroscience noted in this paper. It has also been shown numerous times in studies of motor learning with and without golf being the subject of the study.

SUMMARY AND EXTENSION OF FINDINGS

The studies cited above have provided a basis for the Challenge Point framework. Thus far the framework has suggested four main points:

- Practice performance is not necessarily indicative of learning [1]
- Too much or too little challenge (e.g., task difficulty) hinders learning [3]
- Optimal challenge point is dependent on both the level of the performer [32] and the complexity of the task [33, 34, 25]

This last point leads into the final point of importance from the Challenge Point framework: The optimal challenge point is not static. This point helps guide the development of a dynamic training protocol for golfers.

As noted previously, efficiency of grouping multiple-task elements is dependent on the performer's experience level. The example of an early stage of learner being inefficient in grouping multiple-task elements was used earlier to illustrate this concept. Early in learning, information needs to be presented in smaller units to allow the learner to efficiently process the information. Large units would overwhelm the learner. However, when a performer is in a later stage of learning, the system's ability to group information improves and thus can more efficiently handle a more demanding practice protocol. The overall efficiency of processing information is dependent on relative task difficulty; i.e., the difficulty of the task relative to the individual completing the task. Again, a 3-foot putt may have relatively low difficulty for the expert but high difficulty for the novice golfer. As such, practice protocols should be designed to maintain an appropriate relative task difficulty and this means that the practice should change as the learner changes. For example, for a novice golfer or a golfer learning a new skill, it is appropriate to present KR after every trial or at least every few trials so that the golfer can learn to compare performance with feedback. However, as the golfer gets better at the task at hand they should get feedback less often, thus increasing the task difficulty by making the experienced golfer work out the details of the feedback for themselves. Likewise, a coach might start with constant/blocked practice for the novice golfer but random practice for the experienced golfer. The point is that the golfer needs to be challenged at an appropriate level for learning to occur. Under-challenging the golfer will create a situation of good practice performance and poor tournament performance. Overchallenging will result in poor practice and tournament performance. The idea of maintaining the relative challenge for the golfer by increasing the overall challenge as the golfer progresses is modeled in Figure 3.

Figure 3 demonstrates optimal challenge points for two different golfers (or a single golfer progressing through stages of learning). In the figure, the dotted line represents an early-stage learner and the solid line represents the later stage learner.

In both cases, the basic relationship between task difficulty, learning and performance still exists: Optimally difficult practice yields less-than-optimal performance during practice, but promotes efficient learning. However, the point at which a performer is optimally challenged differs by skill level. For example, challenge point A represents a blocked practice situation where the golfer hits 15 balls in a row with the same club. For the novice golfer, the blocked practice will be somewhat challenging during practice performance and will facilitate learning. The same blocked practice for the experienced golfer will not be very challenging. As a result, practice performance may be quite good but little learning will take place. This is quite different from what would happen with challenge point B. In this case, practice is randomized such that every shot is with a different club. For the experienced golfer this may be appropriately challenging, but for the novice golfer this protocol will be overwhelming and both practice performance and learning will suffer. Based on the relationship between expertise and appropriate challenge, it can be surmised that task complexity should increase as the performer becomes more proficient at the task. In this regard, the relative task difficulty – i.e., the difficulty of the task relative to the individual who performs it – is maintained.

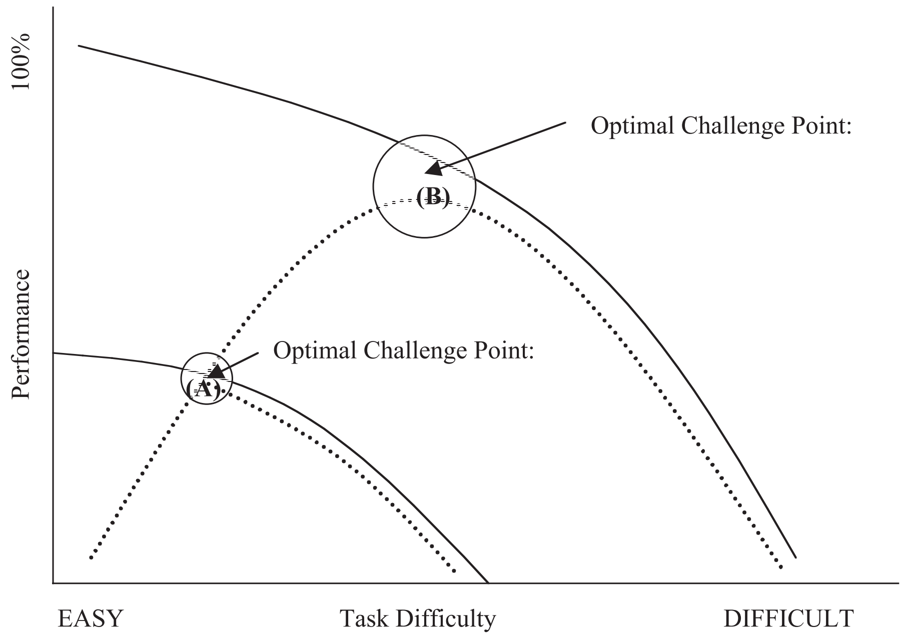

Figure 3. The Hypothetical Relationship Between Practice Performance and Retention Performance for Differing Levels of Task Difficulty and Differing Levels of Performer Experience
(A) Represents a Performer in the Early Stage of Learning
(B) Represents a Performer in a Later Stage of Learning.

Within a task, an individual's stress may be impacted by a variety of practice protocol manipulations. For example, changing the frequency or immediacy of feedback or how often shots are changed can affect one's stress. These manipulations should match the performer's ability. That is, in an early stage of learning, the system is inefficient in grouping multiple-task elements. Therefore, the information needs to be presented in more appropriate units for efficient processing. Situations such as a shorter summary KR length or less practice variability may provide information in more appropriate units for the novice.

Each of these practice methods (e.g., shorter summary KR, and less practice variability) results in decreased perceived stress. For the novice golfer, these methods lead to more efficient learning because the early-stage learner is not overly stressed. Likewise, when a performer is in a later stage of learning the system's ability to chunk information improves. One can more efficiently handle a more demanding practice protocol. The late-stage learner also has a more stable cortical activation network associated with performance of the skill, which results in less stress response associated with more difficult practice situations. Therefore, the experienced golfer can handle more stress and should handle more stress for efficient learning. The basic formula for learning success suggests that the overall efficiency of processing information is based on relative task difficulty, which is based on the level of the performer and the complexity of the task.

CONCLUSION

By combining the laboratory and field research presented with the Challenge Point framework, it can be concluded that for efficient learning the individual must be appropriately challenged during practice and this challenge must change as the learner becomes more skilled. For example, early in learning feedback (KR) should be frequent, but as the learner progresses the frequency of feedback should become less frequent. Likewise, early in learning there should be little imposed task variability, yet as the learner becomes more adept the variability of the task should increase to maintain the relative task difficulty and appropriate challenge for the individual. This method of practice is likely to challenge the golfer during practice, but it might at times be discouraging. This same practice structure that produces a challenging situation during practice, however, will produce optimal learning as seen on the course. By explaining this basic principle, it is likely that most golfers will sacrifice immediate rewards on the practice range for long-term rewards on the course.

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