

Hull's Quantitative Equation on Human Performance

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Abstract

Wilson, J. A Classic Review in Exercise Science – Hull's Quantitative Equation on Human Performance. *Journal of HYPERplasia Research* Volume 5, No. 2, 2005. Hull (1943, 1952) attempted to define performance in a way which could be clearly measured, and more importantly laid the ground work for predictive theoretical constructs on the subject. It can be argued that most modern theories, such as the Banister (1975) fitness fatigue theory of the taper can be traced back to Hull's work. In this context the Hullian theory of performance will be clearly reviewed. Practical applications include: increased skill acquisition, and methods dealing with the link between motivation and training. Special emphasis is placed on the concept of Reactive Inhibition. A transient fatigue state which is postulated to mask gains obtained from training. By clearly understanding how to remove this state, athletes are predicted to reach peak performance.

Introduction

Performance can be a nebulous term and must be defined operationally. Some of the earliest endeavors into human performance were issued by a group of scientists known as the connectionists, or behaviorists. These scientists studied the psychology of learning, which is a precursor to the study of motor learning, the latter of which is associated with enhancing the skilled aspects of athletics. This includes both precision skills such as a golf swing, as well as gross motor tasks such as the squat or bench press. The connectionists were so called because they felt that the acquisition of a skill (learning) required the formation of a bond between a stimulus and a response (Hergenhahn and Olson, 2005, Schmidt et al., 1999). The stimulus could be a pitch in baseball, with the response being a perfectly executed swing, or a most muscular pose during a bodybuilding contest. In this context performance was measured as the proportion of correct responses to a given set of stimuli (Hergenhahn and Olson, 2005). They were known as behaviorists because they were empiricists, meaning that they had to see the results and manipulations of their experiments. This required clear observation of behavior or performance (Skinner, 1974, 1978, 1988). It was thought that learning could be inferred through behavior. Sawyer (2004) stated that 'typically learning can be defined as a change in the capacity of an individual to express skill, that must be inferred from a relatively permanent change in performance as a result of practice or experience.' Note that Sawyer (2004) emphasizes the permanent nature of skill acquisition. However, it is clear that performance within an individual itself is variable. Schmidt (1999) refers to the variability (or instability) of performance within an organism as 'noise.' Therefore though learning / skill acquisition is relatively permanent, other factors must also affect movement behavior (Schmidt, 1999).

Under this framework arose Clarke Hull, unquestionably one of the greatest scientists of the past century. He endeavored to mathematically quantify what performance actually was. The purpose of this paper was to review this Hullian theory, as it lays the ground work for the training technique known as tapering.

Hull (1943, 1952) denoted performance as the 'reaction potential (sE_R)' of an organism. The reaction potential was defined as the probability, and speed with which a behavior occurred to a given stimulus. The entire equation is presented as follows:

$$sE_R = (sH_R \times D \times K \times V) - I_R - sI_R - sO_R$$

Where sE_R is reaction potential, sH_R is habit strength, D is drive, K is incentive motivation, V is stimulus dynamism, I_R is reactive inhibition, sI_R is conditioned inhibition, and sO_R is the oscillation of reaction potential. The following paragraphs systematically break down each of these components and apply them to athletic performance.

Habit Strength (sH_R) and Drive (D)

Hull (1943, 1952) defined habit strength as the strength of the bond between a stimulus and a response as other connectionists did. The bond was literally considered learning. When applied to athletic skills, the father of motor learning, Franklin Henry would refer to this as 'Sensori Motor Skill Acquisition (Sawyer, 2004).' The bond itself is what is known as an 'intervening variable.' An intervening variable is a hypothetical construct (Sawyer 2004), or a concept which cannot be seen, but is thought to exist from inferred evidence. For example you can see a skill performed, but not view the internal construct which contains the instructions for that skill. The stronger the bond becomes the greater the probability, and precision that the skill will be executed.

S-R

Figure 1 graphically depicts Hull's idea of skill acquisition.

In the above figure the S stands for a stimulus, which can be an internal go signal such as a command to execute a most muscular pose, or an external stimulus, such as a pass thrown in a football game. The R represents the response or performance. Hull (1943, 1952) felt that strengthening of the bond required repeated drive reduction.

Drive is defined as a need state, and in modern terms is denoted as motivation. The need state is suggested to increase the activity of the organism, until the drive is reduced (Hergenhahn and Olson, 2005). For example, if an individual is hungry their activity goes up, they may go to the kitchen and open the cabinet and fix a protein shake. After drinking the protein shake, hunger (a form of drive) is reduced, and habit strength is increased. The probability of making a protein shake next time the individual is hungry has just increased. The strength of the bond will continue to increase each time a response reduces the drive, therefore practice is essential for skill acquisition. Here is an overview of how the process works

Practice (Independent Variable) Effects → Intervening Variable (learning). While learning Effects → Performance (Dependent Variable).

This process can be applied to bodybuilding or any form of athletics in several ways. For example, the more the drive of hunger is reduced with clean foods as opposed to processed, low density foods, the greater the probability that this response will occur. It can also directly affect performance. Flex Wheeler in 1999 exemplified this statement. He had finished a brutal day of training, and was eating a clean meal. His hunger was obvious, and a drive to lower that hunger with a binge must have crossed his mind. The camera man filming him asked if Wheeler was hungry. His reply was that he was 'craving a Sandow Trophy.' Flex had created a need state, and that need state was powerful enough to increase the probability of tightening up his diet as well as maintaining a hardcore training regimen, all for the purpose of reducing the drive of obtaining the Mr. Olympia title. It should also be noted that the greater the drive, the greater the activity of an organism to reduce that drive. This was first examined this with rats. Given two rats who had the same amount of training, the one who had been deprived of food for a greater period of time would be more likely to solve a maze in order to obtain food (Hergenhahn and Olson, 2005).

Janet Spence has postulated that anxiety is a drive utilized by expert professors in order to enhance the learning state of their students (Hergenhahn and Olson, 2005). This anxiety can take the form of a deadline. Recently the abcbodbuilding staff held a bodybuilding contest known as the HYPERplasia challenge (congratulations to our Champions William Ustov, Njari, and MrsMansonOzz!). The challenge lasted three months. The participants had an imposed deadline, and this time constraint increased anxiety. The drive state would be postulated to increase the activity of the participants to enhance their bodybuilding performance. This would include harder training sessions, and stricter diets. Therefore contests or competitive situations should be a constant aspect of an athlete's program (Wilson, 2003). They should set specific dates to reach specific goals, and make the goals challenging enough to add enough anxiety to increase performance. Note however that the anxiety should not be too high, as current theory suggests that this could lead to an actual drop in performance (Yerkes and Dodson, 1908, Hardy et al. 1986, 1990, 1991, 1992). That is, anxiety increases performance to an optimal point, after which it affects performance negatively.

The current author finds it interesting how Hull's predictions fits Tom Platz (1980) behavior perfectly. Prior to the 1980 Mr. Olympia contest, he made the following statement:

*There is a lot of mental training involved in bodybuilding. You have to cultivate your feelings. **It's as if you have a need**, almost like a calling. **An inherent need** for something, that you must do, and you will not be happy unless it's fulfilled. That is where I'm at and that's why I'm here today.*

Here Platz clearly made reference to an internal drive, a need state, which he suggests drove him to train to the extreme levels necessary to participate in the most prestigious contest in bodybuilding.

Incentive Motivation and Stimulus Dynamism

Crespi (1942) had rats run up a ramp to obtain food pellets. In the first experiment, a group of rats were given 256 pellets of food every time they made it up the ramp. After several trials their mean times were recorded. On separate trials the same group of rats were placed on the ramp, only this time the reward was relatively small at 16 pellets. It was found that running time or performance significantly decreased. Likewise when rats were first exposed to 1 pellet and then switched to 16, they ran faster on the latter. Based on this evidence, as well as other experiments (Crespi 1944, and Zeaman, 1949, Woodworth et al., 1954) Hull (1952) added incentive motivation (K) to his equation. Incentive Motivation refers to the size of the reward presented to the participant for eliciting a given response to a specific stimulus.

Hull's theory would explain why athletic performance can raise in the playoffs to a greater extent than regular season play, as the incentive motivation of each game has risen. It is not necessarily because the players' habit strength or skill has improved. It also displays the importance of utilizing incentives to enhance performance in athletics.

Stimulus Dynamism or (V) refers to the saliency or clarity of the stimulus. The clearer the stimulus, the greater the probability of the response. This is displayed in the outfield in baseball when an athlete attempts to catch a pop up. The probability of them making a catch is higher if the sun is not in their eyes, and the ball can be seen clearer.

Reactive Inhibition (Ir), Conditioned Inhibition (slr) sOr

Hull was the first to examine the effect of massed practice. Massed practice can be defined as practice in which work is longer than rest periods (Schmidt, 1999). In weight training this would entail 1 minute sets, with only 30 seconds of rest between sets. Several reviews on the subject (Lee and Genovese, 1988, Newell et al. 1988) support what is known as Hull's 8th postulate. Hergenhahn and Olson (2005) summarize the 8th postulate as follows: 'Responding Causes Fatigue, which operates against the elicitation of a conditioned response.' This is known as reactive inhibition. Reactive inhibition entails the organism reacting to inhibit the action which caused fatigue. Bourne and Archer (1956) had 5 groups perform a tracking task with 0, 15, 30, 45, and 60 seconds of rest. It was found that as rest increased that performance increased. Of particular interest is that performance was severely depressed in the zero second condition, however after a day of rest performance had risen drastically from the end of the last trial.

The effect of improving in the absence of practice is known as reminiscence (Hergenhahn and Olson, 2004). This effect denoted by Hull provides the current basis for tapering. According to Hull (1943) suggested that reactive inhibition was masking the positive effects of practice, and a period of rest was needed to dissipate this effect. Today, the taper is defined as a period of rest, or lowered training load prior to competition meant to enhance performance (see the Wilson and Wilson 2005 analysis of the Taper).

Hull (1943, 1952) also found another effect. He found that if practice continued without drive reduction that the response would go to extinction (the organism would stop responding). However, as figure 3 displays the response would regenerate with heightened amplitude after a period of rest. He further noted that if extinction were

continued over several days (or longer) that the spontaneous generation of the response that occurred after rest would actually lower with each subsequent period of rest. The effect was denoted as conditioned inhibition. In postulate 9, Hull suggested that reactive inhibition produced a negative drive state. The drive state was negative, as lowering it required the organism to lower activity. Upon a lowering of activity the drive was reduced, which strengthened a learning response. This learning response is known as conditioned inhibition. An illustration can be seen when students enter what they deem as a boring class. Almost involuntarily they begin to yawn. Therefore according to this postulate, reactive inhibition can be conditioned, if practice occurs without reinforcement

(Drive reduction). This may explain burn out. Athletes often set up goals which could take years to reach. They work incessantly towards the goal, but reinforcement or drive reduction will not occur until years of persistence have taken place. Under these conditions the behaviors associated with optimal performance will go to extinction, or be masked by conditioned inhibition. In this context, Knowlden (2004) suggests participants to set up short term goals, or smaller need states which can be reduced frequently. Further, it is also important to keep training fresh according to the Specificity Hypothesis. This hypothesis states that fatigue is specific to the system or effector (body part) fatigued (Payne, 1979). In this context Payne (1979) investigated whether reactive inhibition in one effector had negative effects on a second effector. It was found that the effect was specific to the limb used. This suggests that an athlete can avoid conditioned inhibition by properly sequencing their workouts and training splits. This means that performing the same routine consecutively for weeks on end would produce fatigue specifically to that routine. Routines normally follow an asymptotic curve:

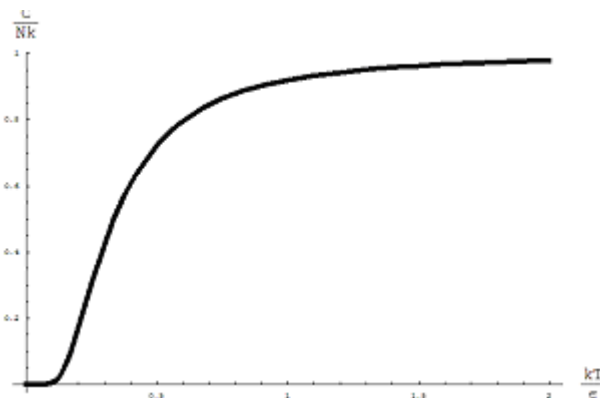


Figure 4 graphically depicts an asymptotic curve. The vertical axis represents performance, and the horizontal axis represents total trials.

The vertical axis represents performance, while the horizontal axis represents the amount of trials or practice sessions that the routine has been performed. Note that as time increases, performance increases decreases. Zatsiorsky (1995) refers to this as the biological law of accommodation, which states that the response of a biological object to a given stimulus decreases over time. If performance is viewed as drive reduction, then consecutive sessions without performance increase can lead to conditioned inhibition. By changing the routine to (A) dissipate the reactive inhibition and (B) work on another area which has not been affected by the fatigue the participant can avoid conditioned inhibition. Such a concept is a form of

periodization, which attempts to break a number of skills and competencies into manageable components.

Oscillation of Reaction Potential (sOr)

Even with all of the other variables taken into account, there were times in which organisms were not perfectly predictable in Hull's experimentation. Therefore he added another variable into his equation known as the oscillation of reaction potential. He postulated that an unseen threshold existed that varied from moment to moment. This threshold had to be exceeded by the positive factors in the equation in order for the response to occur. The applicability of this is not as obvious as the other variables. It does however introduce the concept of noise into the motor system.

Summary

Hull attempted to quantitatively define performance as a function of habit strength, drive, incentive motivation, stimulus dynamism, reactive inhibition, conditioned inhibition, and the oscillatory threshold. Manipulation of each of these variables has been experimentally shown to predict the probability of a response to a given stimulus. It is advised that the athlete takes special care to master these concepts to reach his or her peak during competition. Perhaps more importantly is the suggestion that this theory lays the ground work for modern explanations of how to predict performance. The main of which is the Banister et al. (1975) two factor theory of performance (See Wilson and Wilson, 2005 for a review).

References and Sources Cited

1. Crespi, L. P. (1942). Quantitative variation in incentive and performance in the white rat. *American Journal of Psychology*, 40, 467–517.
2. Schmitdt, R, Timothy L, *Motor Control and Learning*, 3rd edition: Human Kinetics 1999
3. Hergenhahn, B. Matthew, O. *Theories of Learning*, 7th edition: Pearson Education, 2005
4. Skinner, B. F. (1974). *About behaviorism*. (New York: Knopf)
5. Skinner, B. F. (1978). Why don't we use the behavioral sciences? *Human Nature*, 1, 86-92.

6. Skinner, B. F. (1987b). Whatever happened to psychology as the science of behavior? *American Psychologist*, 42, 780-786.
7. Sawyer, D. (2004) Seminar in Sensori Motor Skill Acquisition. California State Hayward University.
8. Wilson, J. (2003) Conflictive Shock Training. *Journal of Hyperplasia Research*.
9. Hardy, L. (1990). A Catastrophe Model of Performance in Sport. In J. G. Jones & L. Hardy (Eds.), *Stress and Performance in Sport* (pp. 81-106). Chichester, England: Wiley.
10. Hardy, L. & Parfitt, G. (1991). A Catastrophe Model of Anxiety and Performance. *British Journal of Psychology*, 82, 163-178.
11. Hardy, L., Maiden, D. S. & Sherry, K. (1986). Goal-setting and Performance: The Effects of Performance Anxiety. *Journal of Sports Sciences*, 4, 233-234.
12. Hardy, L., Parfitt, G. & Pates, J. (1992). Performance Catastrophes in Sport: A Test of the Hysteresis Hypothesis. *Journal of Sports Sciences*, 12, 327-334.
13. Zeaman, D. (1949). Response latency as a function of the amount of reinforcement. *Journal of Experimental Psychology*, 39, 466 - 483.
14. Woodworth, R. S. & Schlosbert G. (1954). *Experimental Psychology* (Rev. Ed). New York: Holt, p 667.

15. Lee, T. & Genovese, E. D., (1988). Distribution of practice in motor skill acquisition: Learning and performance effects reconsidered. *Research Quarterly for Exercise and Sport*, 59, 277-287.

16. Newell, K. M., Antoniou, A., & Carlton, L. G. (1988). Massed and distributed practice effects: Phenomena in search of a theory? *Research Quarterly for Exercise and Sport*, 59, 308-313.

17. Hsu S, Payne RB. Effector localization and transfer of reactive inhibition. *J Mot Behav*. 1979 Jun; 11(2): 153-8.

18. Knowlden, A., (2004) Mind Muscle Doctrine *Journal of Hyperplasia Research*.