What do athletes learn when they learn a motor skill?

by Jim D. McClements and Lyle K. Sanderson

Athletes and coaches work hard to develop perfect skill execution. This paper explains a model of skill acquisition that has been the basis of a sport science research project into sprint starting. The model is based on the simple question, What do athletes learn when they learn a motor skill? The goals of the skill acquisition model are to help athletes use their time effectively and to avoid destructive practice sessions. The ideas presented are the result of a sport science research project and applications of the model in track and field, kayaking and cross country skiing practices.

1 Introduction

The model, based on Schmidt’s (1975) Schema Theory, suggests the key to elite performance is subconscious comparison of kinaesthetic feeling to a template of how the athlete expects the skill to feel. If the feelings and expected kinaesthetic template agree, the athlete tells you it felt good. If the feel and template disagree, the athlete tells you something is wrong. The athletes do not know if the template is right or wrong. All they know is whether their movement agreed or disagreed with the template. The paper will explain the model and applications, using Fitt’s three phases of learning. A fourth phase, “revising old habits”, uses this model to help understand why changing a skill is a difficult task. Finally a learning strategy is presented that makes the change understandable and easier to accomplish.

What difference does it make?

Each athlete brings a variety of physical and mental skills and capabilities to sport. In the physical domain, the athlete has levels of strength, flexibility, cardiovascular fitness, quickness, etc. The athlete also has anatomical and biomechanical limits. Training programmes can enhance these up to the athlete’s potential.

There are similar mental learning and performance potentials. Most important to the instructor/coach and learner, is the idea we can only attend to so much information at any one instant. We all understand the concept of focusing our attention during a race or when executing a skill in competition. Mental preparation for competition requires practice in attending to key cues available to the athlete to optimize performance. But what should athletes attend to during practice? If we understand attention limiting factors and what athletes learn when they learn a motor skill, then we can help them use their attention effectively during practice. The individual will practice better and learn faster. It should also help the athlete develop an attentional style to maintain technique during competition.

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What are the factors that limit attention?

"If you chase two rabbits, you won't catch either of them." 
Grounds Keeper, ANZ Stadium, Brisbane

Attention is a complex phenomena. It involves control of focus at any given time. Attention interacts with perception, memory and decision making (cf. Figure 1).

Demands on one area of the system limit what we can do with the other parts of the system. Attention is very much under the athlete's control. KAHNEMAN (1973) suggests that performers control attention in part by their own evaluation of physical and mental demands on their capacity. NORMAN (1968) suggested that we can set our attention based on our perception of pertinence. Pertinence, the importance to skill execution, is set by our expectations and verbal control. We cannot remember a phone number, decide if we have enough money to buy a new car and identify a familiar face all at the same time. However, athletes can consciously control their attentional focus and decide upon what to focus.

2 A model of skilled performance

You cannot teach a man anything. You can only help him to learn it within himself.

In 1971 ADAMS proposed that performers controlled skill execution with a perceptual motor trace and a memory trace. The memory trace is the stored motor programme used to select and initiate the movement. The memory trace is an 'image of acting'. The perceptual motor trace is a reference point or image of what the response is supposed to feel like. It is an 'image of action'. SCHMIDT (1975) extended these ideas into schema theory. A generalized version of this theory is...
Athletes decide what to do (desired outcome) and select an image of acting from their motor skill repertoire. The image of acting develops instructions (motor programme) to be sent to the muscles. This motor programme integrates the desired outcome and the individual's current posture and situation (initial conditions) to develop the motor programme.

The instructions sent to the muscles have an effect and the skill is executed (results). The athletes receive performance information from what they actually did and from the coach's comments (feedback).

The feedback is then compared to what the athletes expected to happen (image of action). The comparison leads to a decision about effectiveness of the motor programme (error labelling). The image of action is a major aspect of what athletes actually learn. It will be the key to the athletes' subconscious control of movement.

The interpretation of the error labelling process (self reinforcement) is the most crucial aspect of skill learning. The interpretation is the athlete's own analysis of success and failure. While the coach's analysis can influence this interpretation, it is secondary to the individual's self reinforcement. If the athlete interprets the motor programme as a success, the individual will repeat the same programme using the same image of acting. If the individual interprets it as a failure, the individual will try something different to become more effective, or lose motivation.

Self reinforcement is the key to effective learning. Reinforcement by coaches, other athletes and significant others only supplements the athlete's self analysis. If the external comments and the internal analysis agree, the athlete will continue to perform the skill the same way that led to these results. If the individual disagrees, the level of trust the athlete has in the coach and his/her own self confidence will determine the net effect. This is likely to have less power than when the individual agrees.

But athletes cannot attend to all of this information. It exceeds their attentional capacity. What athletes focus on depends on how well they execute the skill. When they compete, they must make the adjustments as they perform. These adjustments are automatic and are made subconsciously. If questioned, athletes will say that the skill "Felt Right". It is interesting to note that elite athletes almost always celebrate these successes but also report small details that they could have done better or where it "Didn't Feel Right". The individual is processing kinaesthetic or proprioceptive feedback at a subconscious level (Proprioception is a collection of nerve receptors that provide performers with the kinaesthetic feel or body part awareness). Errors are noted for later consideration. This is the key to subconscious execution.

Proprioceptive feedback or kinaesthesia is the basis of the image of action. Attending to kinaesthesia while practising leads to the development of subconscious movement control. This subconscious control of skilled execution allows athletes to attend to other dynamic aspects during competition. Subconscious or automatic control occurs if the kinaesthetic feedback matches the image of action. This subconscious control allows optimal performance in challenging or demanding situations such as competition.

2.1 Getting the idea of a skill – concept of task phase of learning

When athletes are beginning to learn a skill they do not have images of acting or action. The coach provides instruction and the athletes work out a motor plan which is the image of acting. To evaluate effectiveness, the athletes depend on the consequences of the action and the coach's feedback. The athletes develop a motor concept of how to do the task. In this phase the useable feedback is called knowledge of results or KR (see Figure 3 next page). KR is information about the consequences of action. How far did the shot travel? Did the javelin land point first?

Athletes do not have an image of acting or image of action. In fact they try a variety of ways of executing the skill, until they find one that works best for them. They can only analyze the image of acting by the outcome of that attempt or KR. Until they execute the skill correctly there is no point in their considering proprioceptive or kinaesthetic feedback during this phase. Attending to it would distract from their development of the image of acting. In fact if athletes have previous experience with related skills, then using those images could lead to negative transfer. It could interfere with learning the new skill. Once the athletes are executing the skill effectively they should move on to the next phase of learning.

The coach's role should be to provide a good model of the skill and to provide prompts and ideas to help the athletes develop a sound basic motor plan or an image of acting.

2.2 Refining the skill – refining phase of learning

Once athletes know what they are trying to learn and a motor plan for executing the skill is
developed, they practise to refine the skill with the goal of subconscious execution. The relevant feedback is now the knowledge of performance (KP). This is summarized in Figure 4. KP relates to the movement details themselves. The athlete might ask "Did I lift my legs?" or "Did I follow through after the release?"

There are three sources of KP: 1) what the athlete can see or hear; 2) what the athlete feels; 3) what the coach tells the athlete. What the individual sees and hears is very important but is always processed at the conscious level. To function at the subconscious level the athlete must learn to analyze and self reinforce the proprioceptive or kinaesthetic feedback. While part of what the individual is doing is fine tuning the motor programme or image of acting, the more important learning is the image of action or the proprioceptive template for error detection. By focusing on the image of action, it will eventually become sub-conscious, which will allow the athlete to perform effectively during competition. The subconscious processing enables the athlete to attend to the event's other demands. The athlete is fine tuning the execution and learning the image of action.

The coach's role is to direct athletes to kinaesthetic feedback and to help them with analysis and self reinforcement. The key is to develop a good image of action. One way to do this is through the questioning-feedback technique discussed below.

2.3 Automated execution - subconscious phase of learning

Sub-conscious control of skill is the key to elite performance. Figure 5 represents the subcon-
scious execution phase. Feedback allows the athlete to adjust subconsciously and to attend to the other competitive issues. The athlete depends on the image of action learned in the refining phase. The test of subconscious execution is to deal successfully with other factors while performing. To be effective, practising must simulate competing, with stressors similar to those met in competition, including fatigue and tactical demands.

Competing athletes analyze performance and if there is "an error" (it didn’t feel right) they become aware of differences between kinaesthesia and the image of action. In the short term, they adjust to the difference. If athletes cannot or do not adjust, they identify this as an area that requires attention before the next competition.

The coach helps athletes with their self analysis. If the athletes’ analyses are appropriate, it is critical to reinforce them at this opportune moment. Coaches can assist the athletes to plan appropriate practice strategies. The coach can also help athletes make these changes in the next few practices. In this way coaches and athletes work together to achieve a common goal.

2.4 Revising an old habit - relarning phase of learning

Modifying a bad habit is a frustrating task. Athletes and coaches, driven by early success, often ignore or even reinforce a bad habit. Early success fuels the self reinforcement. Other bad habits come from modelling successful athlete’s techniques which are biomechanically inappropriate for the individual learning the task.

When an athletes execute a well learned skill that they are trying to change, the subconscious analysis concludes that the skill has been properly executed. In simple terms, it feels right, but the athlete knows it is wrong. When the athlete tries the newer and better way, the subconscious analysis concludes that it feels wrong. Clearly the athlete is in a no win situation.

What feels right is wrong and what is right feels wrong.

To make matters even worse, the athlete is often overwhelmed with conflicting information from the coach, the knowledge of results, the knowledge of performance, kinaesthesia and error information. This is illustrated in Figure 6 (next page).

In this situation self reinforcement is never positive. The situation gets worse when athletes compete. If they execute the skill the newer and better way, they will be constantly detecting errors. They cannot relax and go with the flow and performance will deteriorate further. In order to deal with the errors the athletes will have to direct their attention to execution. Attending to the skill execution means that they will miss other competitive factors, which will further erode performance. The net result is that, at best, they will not feel comfortable and too often they will compete poorly. This is not positive reinforcement. It is frustrating. Good competitors will not tolerate these feelings and will revert back to the old habits, which, in their mind, are their old strengths. The athletes are overloaded with information and none of it is positively reinforcing.

The coach has the challenge of helping athletes understand the problem of what feels right is wrong and what is right feels wrong. The coach must also emphasize and reinforce the
newer execution. The coach must provide more information to complement the athletes’ self analysis, to help them focus on changing the skill. Coaches should allow athletes to tell them what they are trying to do and how well it worked.

2.5 Coaching for high level automated performance

Coaches teach athletes skills and the athletes learn these skills. In the traditional method, the coach tells the athlete what to do. The athlete tries to do the skill the new way and the coach tells the individual what was done right, what was done wrong and what to try next.

An alternate strategy was investigated in 1979 by Murray Hall. This study compared the traditional error correction model of teaching with a questioning-feedback technique. For the traditional method, the coach told the learners what they needed to correct after each trial. With the questioning-feedback technique, the learners were asked to do their own analysis and decide what to try next. The coach listened to the learners and reinforced their decisions or made suggestions. Hall found that the questioning technique led to better performance, better technique and better understanding.

The coach’s role is to help athletes analyze what they did and to help them decide what to try next. The questions direct the athletes’ focus and put athlete and coach on the same page. The coach directs the athletes to the images of acting and action, which are what they are learning. In the concept of task phase, the questions should direct the athletes to the knowledge of results and what they did to make that happen. In the refining phase athletes are directed to their knowledge of performance and, in particular, how the skill felt. This is the kinaesthetic feedback and the image of action which the individual will use in the subconscious execution phase. In the relearning phase this technique helps the athlete recognize the problem of what feels right is wrong and what feels wrong might be right.

2.6 Questioning-feedback technique

Are the questions more important than the answers?

The right questions might be more useful than the right answers. The purposes of the questions are: 1) to get athletes to commit to practising every trial with intent; 2) to focus the athlete’s attention on the kinaesthetic information and 3) to involve athletes in the decisions about what is being learned.

The following four questions have been used with success. The tone of the question is every bit as important as the question itself. The tone helps to create the positive environment for learning. Once coaches have tried the technique, they should develop their own questioning strategy.

Four Possible Questions:
1) What are you working on?

This question helps ensure that you and the athlete are working together. It is very frustrating for any of us to be focusing on one part of a skill and then be told another part is wrong. While error information is both well intended and useful it does not help with the athlete’s self analysis of the most recent trial. At best this trial
is wasted and there is the risk of reducing motivation.

2) Did you do what you wanted to do?
Sometimes athletes try to change the skill, but know that it did not work. They know what they want to try next. Telling them that it was wrong is not really very useful and can detract from self motivation. Most of the time athletes just need another chance to try it again. If an athlete does not know what to do, then the coach might suggest an alternative strategy.

3) How did it feel?
This question directs the athlete's attention to the proprioceptive sensory information. This is the information that the athlete will use at the subconscious phase in competition. Another benefit of this question is that the athlete never knows when you are going to ask it. No one really wants to answer "I don't know". Therefore the individual will analyze every trial.

4) What are you going to try next?
This allows the athlete to take more responsibility for the learning. Practice with intent is the key to improving skill. This question helps the learner to make every trial a useful one. Deciding what to focus on ensures that each trial is productive.

When athletes can answer any of these questions, the coach has a well founded reason to praise them. There is no doubt that the athletes are making the effort. This is positive reinforcement and affects the learning rate and, perhaps more importantly, maintains or improves self motivation.

2.7 How should the coach respond?

a) If the athlete replies "I don't know"
This is a common response when you start using this technique. The key here is to have the athlete do the analysis. Simply ask the athlete: "Can you try it again?" Given that most of us want to help the athlete after every trial, it is difficult to have the individual do it again without comment. However, the important thing is to have the athlete focus on the task of learning the skill.

b) If athlete's analysis is not quite right
Now is the time for your input, but as a teacher. You have the choice of letting the individual try it again with focus or you can re-teach the skill.

The coach is encouraged to involve athletes in the learning process as much as possible. The coach shapes the athletes' behaviour by questioning and directing their attention to the kinaesthetic information. When athletes are confused or overwhelmed, it may be necessary to be more directive and tell them what to do.

2.8 The potential benefits of asking rather than telling
• Every trial can be useful as long as the athletes are trying to learn. They never know when you are going to ask for their self analysis. Therefore the athletes can and will analyze every trial.
• Every comment the coach makes is either related to what the athletes are working on or to helping them to decide what to work on. This insures every trial has a shared focus and helps improve the athlete coach communication.
• Coach and athletes are clearly working together. This builds an environment of mutual respect. There is less frustration and more opportunity for education. The athletes are identifying their own mistakes rather than being told that they did it wrong.
• The coach provides more positive reinforcement for the error analysis as well as the performance. This will complement the athletes self reinforcement. Learning will occur and self motivation will remain high.

2.9 An example of using these techniques
The questioning-feedback technique was used in a sport science project that provided force feedback to help improve sprint start technique. Immediate, accurate feedback was used to help the coach and athletes to analyze starts and to revise technique. The next section will briefly illustrate these results. The techniques developed in these projects have been applied by coaches in normal practice settings without the technological aids.

Saskatchewan Sprint Start Apparatus
The Saskatchewan Sprint Start Apparatus allows coaches and athletes to receive almost immediate force/time feedback to evaluate sprint start technique (SANDERSON, McCLEMENTS and GANDER 1991). The athletes start on instrumented blocks interfaced to a computer. When they return to the blocks the force time curve is displayed on the computer monitor. The Saskatchewan Sprint Start Apparatus has been proven a reliable and valid measurement tool (GANDER et al. 1994).

In an earlier study, the horizontal force was identified as the factor most highly related to effective sprint starts (McCLEMENTS, SANDERSON and GANDER 1996a). In a controlled learning study, club level sprinters proved that immediate accurate feedback of horizontal force improved group sprint starting performance (McCLEMENTS, SANDERSON and GANDER 1996b). The example used here is an individual application of the same techniques.
Ideal force/time signature

Athletes exhibit a fairly consistent force/time curve, called a force-time signature. A typical force/time curve is illustrated in Figure 7a. When you examine this force/time signature, there is a dip in the total horizontal force curve as the foot leaves the rear block. This is illustrated in Figure 7b. The coaches and consultants decided that this dip was not as effective as the "ideal force/time signature" illustrated in Figure 7c.

3 Case study

The coach and athlete were using the Saskatchewan Sprint Start Apparatus to improve starting technique. The goal was to change the starting technique to produce an "ideal force/time signature", as defined above. The athlete did a start, reviewed the curves with the coach and decided to try a different technique. When he returned to the computer monitor, he was asked "How did it feel?" or "Did you do what you tried to do?" The coach responded and then they reviewed the force-time curve.

A dramatic change occurred over ten trials. This is illustrated in Figure 8a and 8b. With ten starts the dip in the force time signature was removed. When technical modifications are made one can normally expect a short term decline in performance until the skill is mastered, and then performance gains will occur. In this case, while the shape of the force/time signature changed, there was no loss in the output factors, such as reaction time, block time, departure time, impulse, departure velocity and acceleration (see Table 1). In fact, if anything, these variables marginally improved. The departure time is slightly faster, which is a one time gain of 0.01sec and the calculated or theoretical acceleration is slightly faster by 0.29m/sec².

The combination of immediate feedback and questioning technique after each trial helped the athlete change his force time signature after only ten starts and at the same time marginally improved the athlete’s start performance.

4 Summary

This paper summarizes a performance model that was used in a series of sport science studies. The model suggests that what athletes learn is the image of the kinaesthetic feel of the movement. If the kinaesthesia matches the image, then the athletes will tell you it feels good. If the kinaesthetic feel and image are different they will tell you something is wrong. The paper explains the model and what athletes uses to learn over four phases of skill acquisition. A

<table>
<thead>
<tr>
<th>Before</th>
<th>After</th>
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<tbody>
<tr>
<td>Reaction time [msec]</td>
<td>160</td>
</tr>
<tr>
<td>Block time [msec]</td>
<td>310</td>
</tr>
<tr>
<td>Depart time [msec]</td>
<td>470</td>
</tr>
<tr>
<td>Impulse [n/sec]</td>
<td>250</td>
</tr>
<tr>
<td>Depart velocity [m/sec]</td>
<td>3.57</td>
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<tr>
<td>Calculated acceleration [m/sec²]</td>
<td>11.26</td>
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Table 1: Output factors
questioning-feedback technique was used to help the athletes direct their attention to this feedback.

The model has been used in a controlled learning study and in one to one situations, where the Saskatchewan Sprint Start Apparatus was used to document the success.

![Figure 8a: Series of starts with force feedback and coaching for "ideal" force/time signature](image1)

![Figure 8b: First and tenth start with horizontal force feedback and coaching for "ideal" force/time signature](image2)

REFERENCES

ADAMS, J.A.:  

FITTS, P.M.:  

GANDER, R.E.; MCCLEMTENS, J.D.; SANDERSON, L.K.; ROSTAD, B.A.; JOSEPHSON, K.L.; PRATT, A.J.:  

HALL, M.:  
The effects of two types of feedback on motor skill acquisition. Unpublished masters thesis, University of Saskatchewan, Saskatoon, Saskatchewan 1979

KAHNEMAN, D.:  

MCCLEMENTS, J.D.; SANDERSON L.K.:  

MCCLEMENTS, J.D.; SANDERSON L.K.; GANDER R.:  
Research into Sprint Start, Kinetic and Kinematic Factors. A Technical Report to the International Athletic Foundation 1996a

MCCLEMENTS, J.D., SANDERSON L.K.; GANDER R.:  

MCCLEMENTS, J.D.; SANDERSON L.K.; GANDER R.:  

NORMAN, D.A.:  
Toward a theory of memory and attention. Psychological Review, issue 75 (1968), pp. 522-536

SANDERSON, L.K.; MCCLEMENTS, J.D.; PATZER, C.; GANDER, R.E.:  
Development of apparatus to provide immediate accurate feedback to sprinters in a normal training environment. New Studies in Athletics, London, 6 (1991), 2, pp. 33-41

SCHMIDT R.A.:  