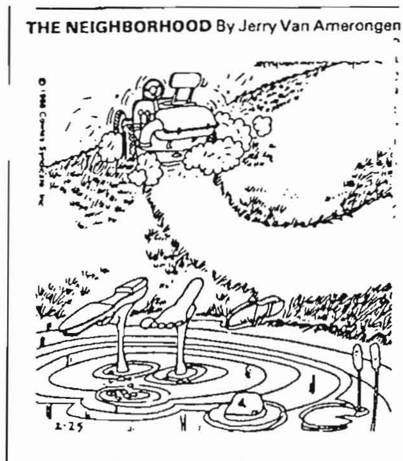
BIOMECHANICS AND MOTOR CONTROL

BIOMECHANICS AND MOTOR CONTROL: A MARRIAGE THAT WORKS

Dr. Diane Ross

Introduction

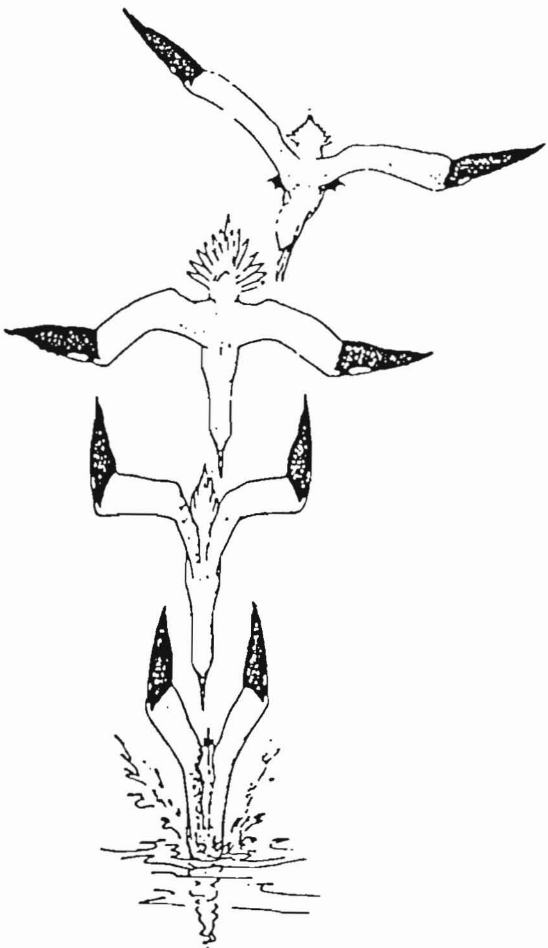
It is a pleasure for me to be here today. I think I was invited to present because I have always been interested in biomechanics and as a graduate student worked as a research assistant in the bioengineering laboratory. In addition, we are doing some work in our laboratory which supports what I am going to discuss today.



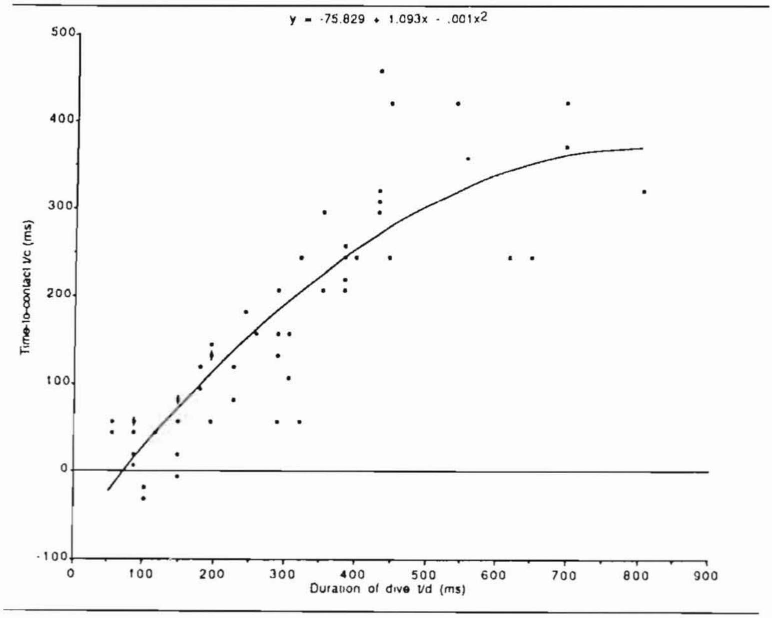
Another victim of physics.

Although this is not what we are doing, it looks to me as if this is a question which a biomechanist might try to answer, however there certainly is a motor control problem here.

Diving for fish: The eyes have it



Likewise, this might suggest a biomechanical question but Lee and Reddish (1981), researchers in Scotland where they have access to these birds, asked a motor control question. How does the gannet know when to close its wings so that it doesn't break its wings as it dives into the water from great heights?



Overhead 3

Analyzing high speed films of the gannets diving into the water, they found that regardless of the distance traveled or the speed of entry, the bird uses time to collision to determine when to close its wings.

In my presentation today I will try to identify research which seems to represent a "marriage that works." And since this is an international symposium I have used research examples from various countries. I will begin by looking at the control of fundamental movements, then move to learning motor skills, after which I will show how this marriage can work in an applied setting using some work we are presently doing in our laboratory.

Walking and Running

Walking and running patterns at the present time appear to be of great interest to motor control researchers. For example, a question asked by Shapiro, Zernicke, Grego, and Diestel (1981) was based on the notion of motor programs. Since it appears to be fairly well documented that relative timing in a motor skill is an invariant characteristic of the skill, that is when a skill is executed either fast or slow the relative timing of the component parts remains constant, it was of interest to Shapiro et al (1981) to determine if the same motor program controls both walking and running.

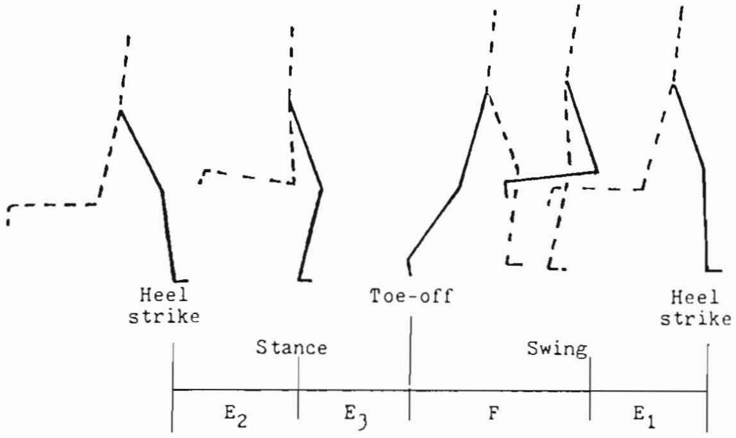
ARE WALKING AND RUNNING

CONTROLLED

BY THE SAME MOTOR PROGRAM?

SHAPIRO, ZERNICKE, GREGOR, and DIESTEL (1981)

To answer this question, they had their subjects walk and run on a treadmill at specific speeds while being filmed using high speed photography. To analyze the data they used the Phillipson step cycle.



Philippson step cycle

In this way they could identify the total time for each step cycle and could calculate from the absolute time of each phase of the Phillipson cycle the component relative times. These component times were then subjected to an ANOVA and the finding revealed significant differences in some of the components.

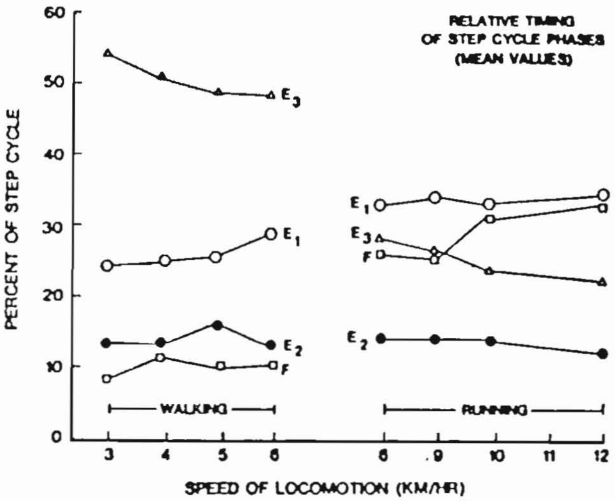


Fig. 4. Relative timing of the Philippson step cycle phases as a function of speed of locomotion.

D.C. Shapiro, R.F. Zernicke, R.J. Gregor, and J.D. Diestel

As you can see the E phase and the E3 phase change rather dramatically. The percent of cycle time in the last part of the stance phase decreases in running while there is a significant increase in the first part of the swing phase.

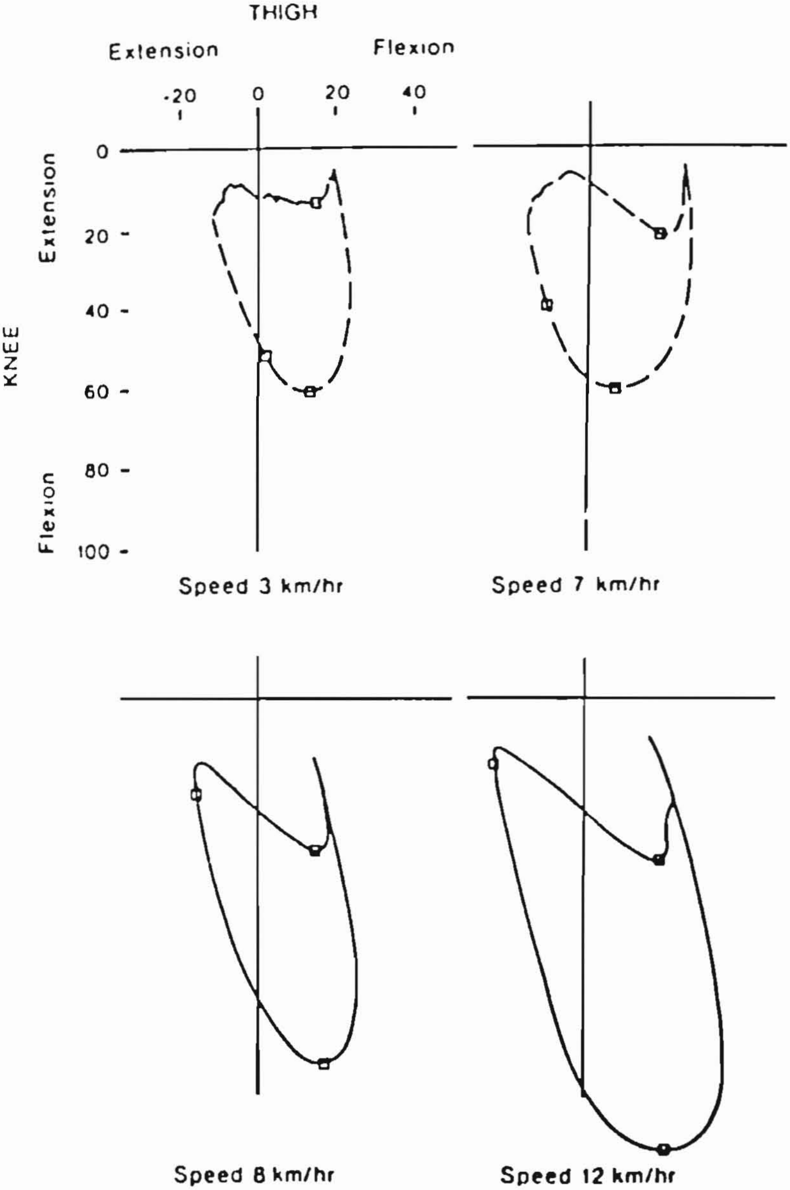


Fig. 5. Exemplar angle-angle diagrams.

The angle/angle diagrams graphically displayed the within similarities of two walking speeds and two running speeds and the differences between walking and running. Thus, the authors concluded, based on these two lines of evidence, that walking and running must be controlled by independent motor programs.

One of my graduate students, Greg Phillips, suggested that since Shapiro et al (1981) used very slow running speeds and since treadmill running is different from track running, it might be that for either fast running speeds and/or sprinting yet another motor program exists to control movements at the higher speeds.

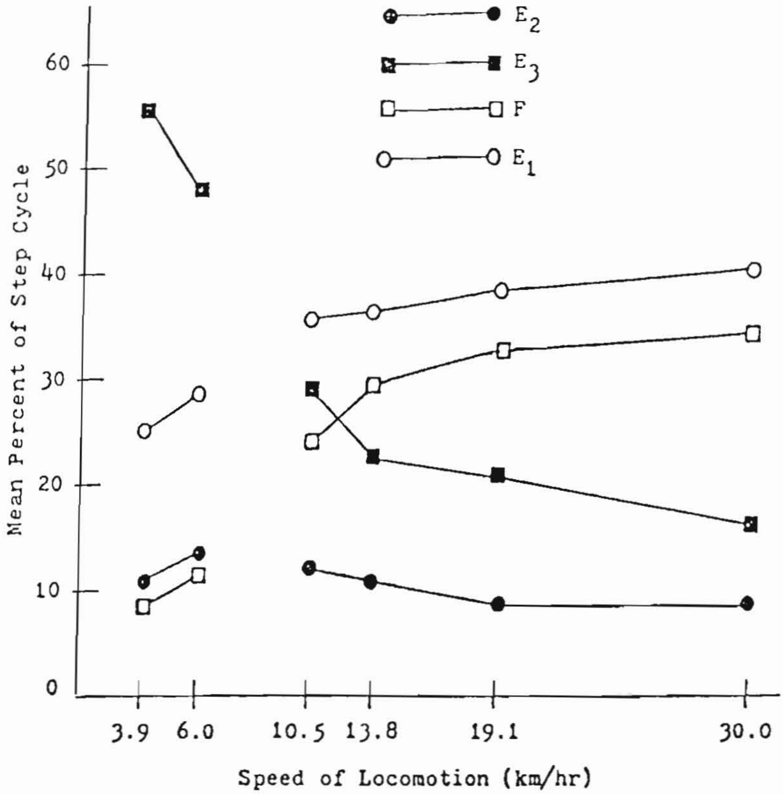
ARE JOGGING AND SPRINTING

CONTROLLED

BY THE SAME MOTOR PROGRAM?

Phillips, 1987

Thus, his question was "are jogging and sprinting controlled by the same motor program?" To answer this he used a 16mm camera, filming at 100 f/s on an outdoor track. His subjects were 3 endurance runners and 3 sprinters. All subjects were filmed at six movement speeds - slow walk, fast walk, jog, slow run, run, and sprint. The two walking speeds were included in order to replicate Shapiro et al (1981). All of the appropriate biomechanical methodological considerations were incorporated in the data collection. Thanks go to Dr. Nelson Ng (Professor of Biomechanics at California State University, Los Angeles) for the computer program he wrote specifically for this study. Using the Phillipson step cycle, Greg was able to digitize the ankle, knee, and hip joints to determine the relative invariance of each of the components of the step cycle.



Relative timing of step cycle segments as a function of speed of locomotion

As you can see there is consistency within the two walks and differences between the walk and run in the F and E3 phases. These replacate the Shapiro et al (1981) findings. However, the multivariate analysis revealed a significant difference between jogging and sprinting for the F and E3 phases, suggesting two motor programs. But since intermediate speeds of running were not significantly different from jogging nor significantly different from sprinting, he concluded that jogging and sprinting cannot logically be controlled by separate motor programs. Thus, running, regardless of speed, is probably controlled by a single motor program.

Walking has continued to be of interest to researchers and in a developmental study, Clark and Phillips (1987) wanted to determine if the invariance in the walking pattern changes as a function of development.

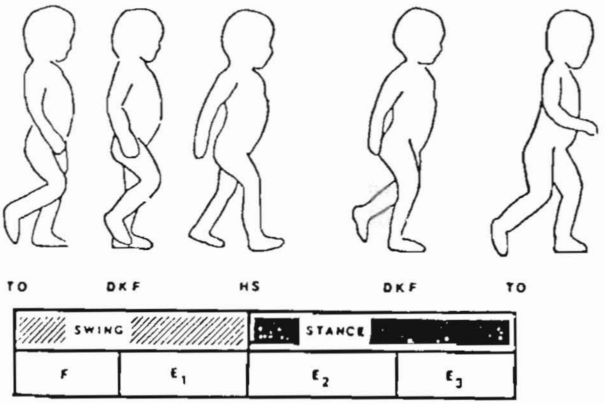


Figure 1. Schematic description of the Phillipson step cycle. (HS = heelstrike; TO = toeoff; DKF = deep knee flexion.)

Using infants who had been walking either 3, 6, or 9 months and an adult control group, the researchers used the Phillipson step cycle to analyze the walking pattern. They found that the relative duration of each phase of the Phillipson cycle was the same for 3 mo., 6 mo., 9 mo. and adult walkers.

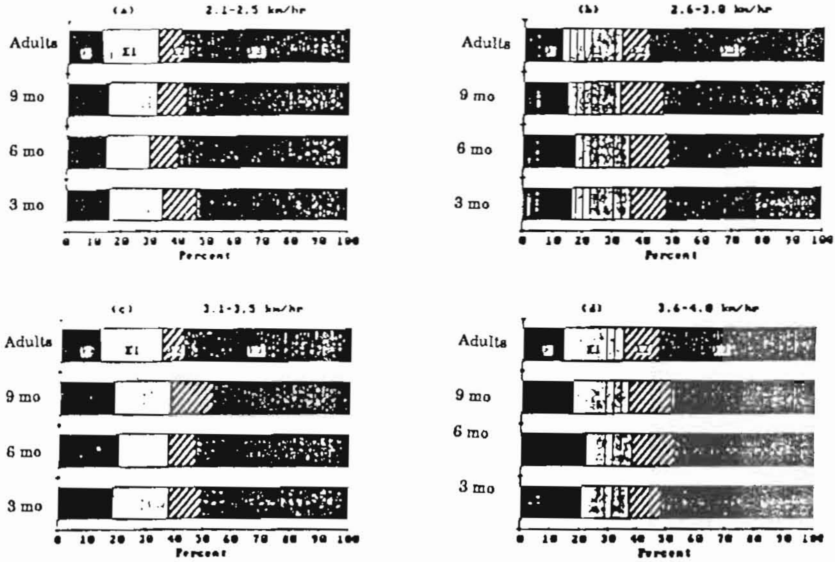


Figure 5. Relative duration of each phase of the Philippson cycle for 3-, 6-, and 9-month walkers and adults at each spe

Thus, we have seen through film analysis that there are regardless of age, invariant characteristics in walking, suggesting that the controlling mechanism may be a single motor program which is established early and maintained throughout the developmental process, while a similar but different relative timing exists in various running speeds.

Bimanual Control

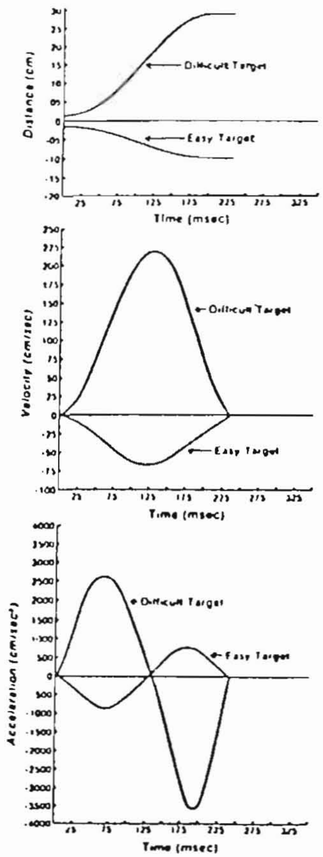
If we turn now to bimanual control there are two papers which I have found very interesting. Kelso, Southard & Goodman (1979) found that when subjects were required to exhibit bimanual movements to varying size targets and movement distances, movement time for each hand was close to being identical. As you can see, the larger targets were considered "easy" while the smaller targets were identified as "difficult."

Mvt. Time	Left Target		Home Keys		Right Target	Mvt. Time
			• •		□	159
151	□		• •			
82		□	• •			
			• •	□		78
89		□	• •	□		85
166	□		• •		□	169
155	□		• •	□		133
140		□	• •		□	158

Movement times for unilateral and bilateral hand/arm movements to easy and difficult targets.

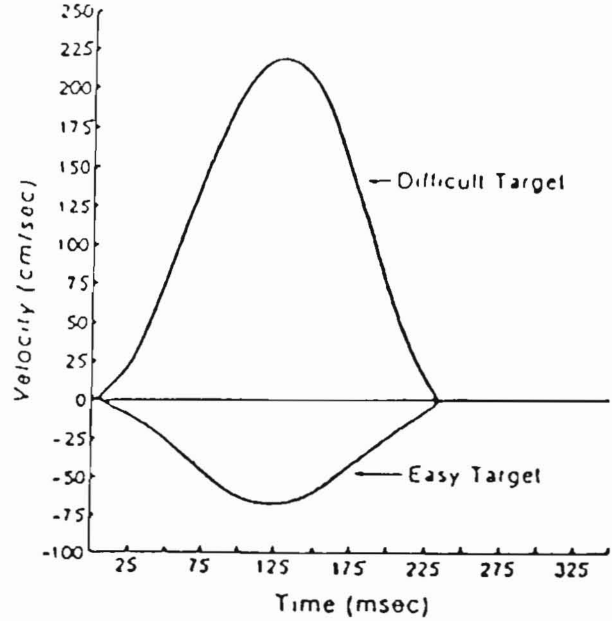
Kelso, Southard, and Goodman (1979)

However, a more interesting finding was exhibited when LEDs were placed on the knuckles of each hand and the actions were filmed. If we look at the displacement, velocity, and acceleration graphs when one hand was required to move to an easy target (short distance-large target) while the other hand moved to the difficult target, (long distance-small target) the shape of the curves are very similar.



Kelso, Southard, and Goodman, (1979)

If we look at just the velocity curves when one hand is required to move to an easy target and the other had to a difficult target, it is obvious that peak velocity is three times greater for movement to the difficult target than to the easy target.



Kelso, Southard, and Goodman, (1979)

However, the interesting motor control question is seen in the time to peak velocity. Even though one hand moved more slowly than the other hand, peak velocity occurred at 125 msec. into the movement for both hands.

These data provide much more information about the way in which the two-handed movements were produced than does the movement time data alone (that both hands reached the targets in 225 msec.). The biomechanical analysis also led to theoretical development regarding symmetrical bimanual motor control.

Viewing bimanual control from a different perspective, Yves Guiard, from France, published a very good theoretical paper in 1987 in which he suggests that, in many motor tasks, (such as dealing cards) there is a asymmetric division of labor. He argues that we have spent years investigating bimanually symmetric hand action, and single hand action, but have given little attention to bimanual asymmetric actions.

KINEMATIC CHAIN MODEL

1. THE TWO HANDS PLAY DIFFERENT ROLES AND COOPERATE WITH ONE ANOTHER AS IF THEY WERE ASSEMBLED IN SERIES, THEREFORE FORMING A KINEMATIC CHAIN.

2. MAY HELP IN UNDERSTANDING THE ADAPTIVE ADVANTAGE OF HUMAN MANUAL SPECIALIZATION.

GUIARD (1987)

From his perspective the two hands play different roles and cooperate with one another as if they were assembled in series, therefore forming a kinematic chain. It is this kinematic chain model which may help in understanding the adaptive advantage of human manual specialization. So we not only have experimental data investigating hand actions but cross disciplinary theory development as well.

Sciaky, Lacquaniti, Terauolo, and Soechting (1987), from Italy, investigated the relationship between the way adults perform a single hand drawing movement and the way that same movement is produced by children. Specifically they wanted to know if the mature pattern is due to developmental factors or learning factors. They used as their task the drawing of ellipses both freehand and tracing a template. Their measurements were ellipsoidal trajectories. Subjects were required to draw both freehand and template traced ellipses repetitively on a digitizing table placed in front of them.

R. Sciaky, F. Lacquaniti, J. F. Soechting, & C. Terzuolo

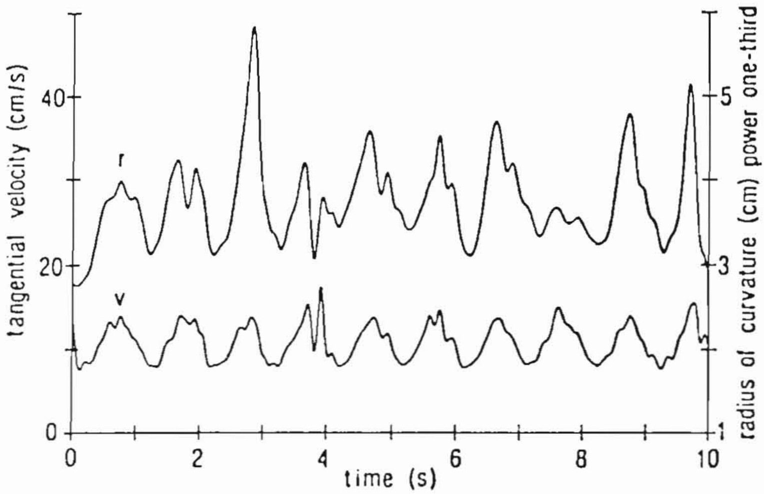


Figure 1. The relation between tangential velocity and radius of curvature is already present in young children. Time courses of the cubic root of the radius of curvature (top trace) and of the tangential velocity (bottom trace) are plotted for a representative single trial from an experiment involving a 5-year-old child.

One of their findings was that the tangential velocity at the pen's tip changes roughly in parallel with the radius of the curvature (power 1/3) of the drawn ellipse. This relationship held for children at various ages as well as adults, however there was a tighter coupling as age increased.

Part II

Thus far I have presented data to demonstrate a limited variety of motor control questions which have been addressed and analyzed through biomechanical methods. It is obvious that greater understanding of possible controlling mechanisms leading to both theoretical and applied implications is provided by these forms of analyses.

Motor Learning

I want to turn now to questions related to learning movement skills. In these studies you will see the use of other biomechanical techniques besides high speed films.

Mulder and Hulstijn (1985), from the Netherlands, investigated the role of different forms of feedback in learning a novel motor task. Five groups of ten subjects had to learn the voluntary control of the abduction of the big toe, with each group under a different feedback condition. The task was selected for two reasons. First, in many motor learning studies subjects have to perform simple movements that present a limited learning problem. Second, studying the learning of a new movement can provide useful information for neuromuscular re-education, which patients often also have to learn movements for which no control strategy exists. On a pre-test all of their subjects were unable to perform abduction of the big toe without moving the entire foot, or the other toes, when asked repeatedly to do so. They had to learn to move the toe on command within 5 seconds and with a range of motion of at least 5 degrees.

TYPES OF FEEDBACK USED IN LEARNING

ABDUCTION OF THE BIG TOE

1. PROPRIOCEPTIVE FEEDBACK (P)
2. VISUAL FEEDBACK (PV)
3. EMG FEEDBACK (PVEMG)
4. TACTILE FEEDBACK (PVT)
5. FORCE FEEDBACK (PVTFORCE)

Mulder and Hulstijn (1985)

1. In the proprioceptive feedback group, subjects were seated behind a screen and were not allowed to see their feet and were given no verbal knowledge of results.

2. The visual feedback group was allowed to guide their response by visually inspecting the results so they actually had proprioceptive feedback plus vision.

3. The EMG feedback was in the form of a continuous visual display of the abductor hallucis muscle output during each 5 second trial.

4. In the tactile feedback condition the subjects could feel resistance from pressing the great toe against a force meter. Thus they received "natural" (subjective) information about the force of the movement.

5. The last group not only had proprioception, vision, tactile, but they were given the force output from the force meter displayed on a TV monitor.

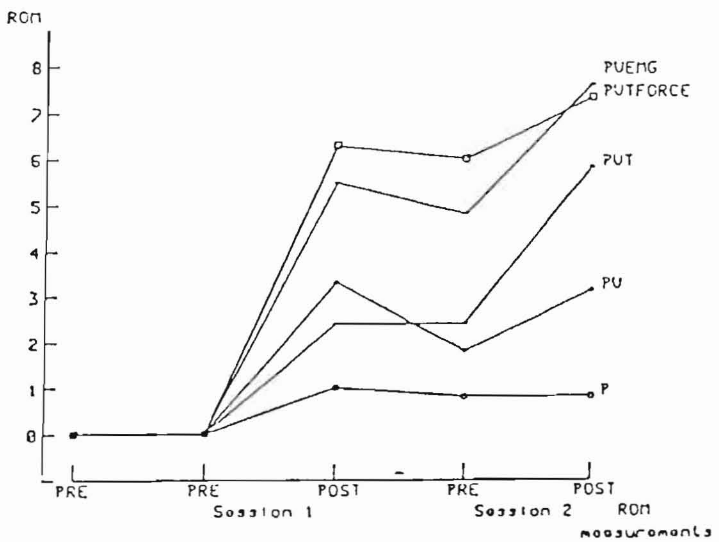
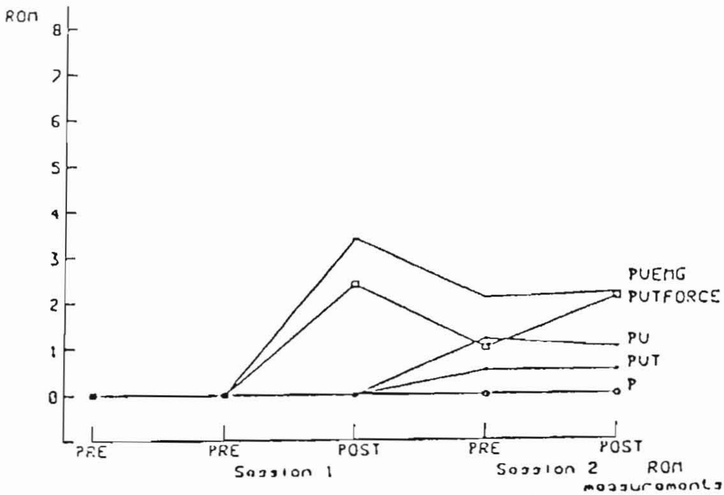


Fig. 1—The mean ROM (of the right foot) for the five training conditions on the pre- and post-tests and on the test performed one week before the experiment started.

Mulder and Hulstijn (1985)

As you can see, being able to see the right big toe helped in learning the task. But dramatic differences were seen when biomechanical feedback information was given to the subject.



ig. 2—The mean ROM (of the untrained left foot) for the five training conditions on the re- and post-tests and on the test performed one week before the experiment started.

Mulder and Hulstijn (1985)

Perhaps these data of the untrained left toe are even more important. The curves are very similar, however, the effect is of a lesser magnitude. I see these results as having major implications for learning new motor skills, assisting to change biomechanically incorrect movement patterns, and, of course, in a re-education therapeutic setting.

Hatze (1976), a biomechanist from Austria, developed a mathematical model to predict the optimization motion for a single subject performing a fast kick to a target. The model included selected anthropometric measures of the subject. The subject wore a mass attached to his boot and this diagram depicts the experimental setting.

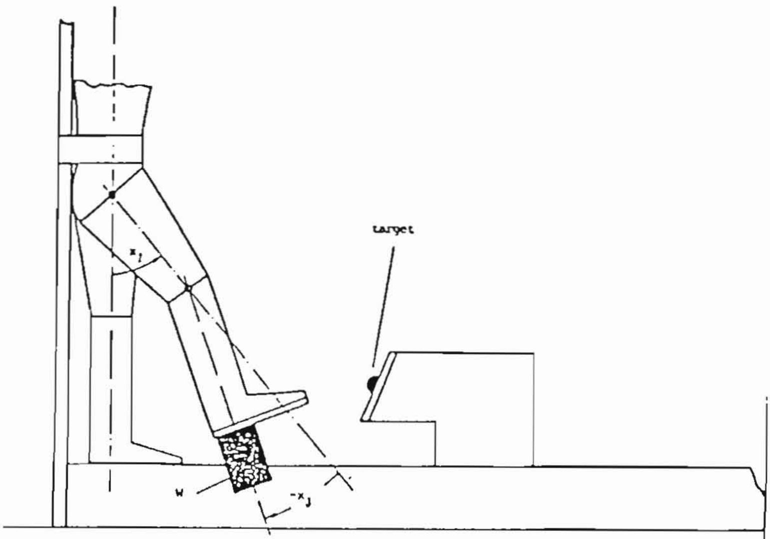
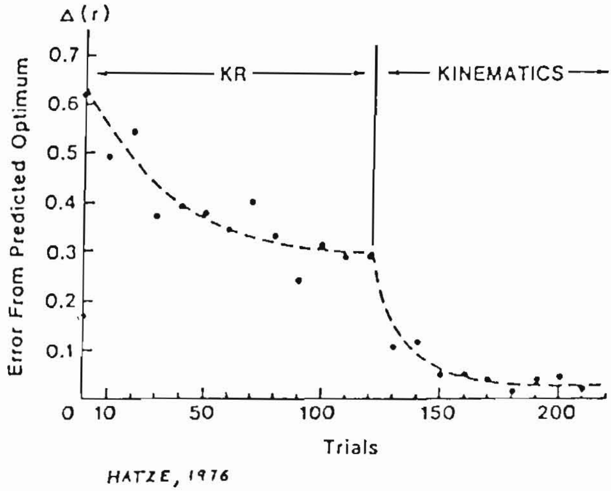


Figure 2. Schematic representation of the configuration of the target and the subject's right leg. The hip angle is denoted by x_1; knee angle by x_3. The symbol W denotes the 10.0-kg mass that is attached to the subject's boot.

The subject was given 120 trials during which he was given the normal knowledge of results (the total movement time of the kick), following which he was repeatedly shown a film displaying the optimal motion as well as superimpositions of the optimal motion on his own performances. As you can see, the first 120 trials the subject displayed the typical learning curve.



However, when the form of the feedback changed to biomechanical information and was compared by the subject to the predicted optimal pattern, the discrepancy between the observed motion and the predicted optimal motion was reduced to almost zero. Although this study contained a n of one, the results were very strong and support the use of comparative biomechanical feedback.

I would be remiss at this point if I didn't mention the work of Karl Newell and colleagues at the University of Illinois who have been attempting to determine what kind of information the learner picks up through observing demonstrations of the motor skill. For example, Scully (1986) showed that gymnastic judges were able to evaluate technical execution and aesthetic quality of a 30-sec balance beam compulsory routine just as well when viewing films of the pattern of moving reflective dots on the gymnastics joints as they did when viewing under normal conditions. That is, it was the kinematic pattern itself which was crucial to the evaluation of perceptual information in judging gymnastics and this had not previously been considered the critical variable. Newell and Walters (1981) stated "that we should systematically be investigating the informational content of the kinetic and/or kinematic information of a skill and how this might interact with the complexity of the task and the skill level of the performer." I suggest to you that many motor control people do not have the biomechanical skills to do this - we need your help!

From a different perspective, Weinberg and Hunt (1976) published what I think is a unique way to investigate the qualitative differences expressed by two kinds of learners: high and low anxious individuals. Using Spielberger's State-Trait Anxiety Inventory, they identified 10 high anxious subjects and 10 low anxious subjects. The task consisted of tossing a tennis ball 10 times at a target consisting of three concentric circles painted on a wall. Subjects were informed that throwing accuracy was very important and accuracy scores were recorded. During each throw EMG activity patterns in the biceps, triceps, extensor carpi radialis and flexor carpi ulnaris were recorded.

WEINBERG AND HUNT (1976)

MEASUREMENTS:

1. THROWING ACCURACY
2. EMG: BICEPS AND TRICEPS
   EXTENSOR CARPI RADIALIS AND
   FLEXOR CARPI ULNARIS

RESULTS:

1. HIGH ANXIOUS DISPLAYED POORER PERFORMANCE THAN LOW ANXIOUS.
2. HIGH ANXIOUS EXHIBITED COCONTRACTION OF AGONISTS AND ANTAGONISTS.
3. LOW ANXIOUS EXHIBITED SEQUENTIAL ACTION OF AGONISTS AND ANTAGONISTS.

They found that not only were the highly anxious subject's performance scores poorer, but their EMG patterns were qualitatively different form low anxious subjects. One of their findings was that highly anxious individuals exhibited co-contraction of agonists and antagonists, while low-anxious subjects exhibited sequential action. To my knowledge, this was the first study to actually demonstrate statistically significant differences on measures, other than those of performance, which reflected neuromuscular patterning differences due to manifested anxiety. Unfortunately, Weinberg and Hunt did not continue with this line of research.

It would be very interesting to see if EMG patterns change as a function of practice on the task. Would the highly anxious subjects eventually produce sequential firing more like the low anxious or would they stay fairly consistent? What kinematic differences exist between high and low anxious individuals? How do they change as a function of learning? Waht effect would EMG feedback have on these measurements in high anxious subjects? It is my hope that some future cooperative efforts among a biomechanist, motor learner and a sport psychologist will continue with this line of research.

Part III

I want to look at some applied studies in which some form of biomechanical information is given to the learner as feedback to facilitate performance and learning. In a very old study, Howell (1956) used as his subjects a college track and field physical education class. These subjects were learning how to get out of the starting blocks as fast as possible. In fact, Howell wanted these students to maximize force against the block as fast as possible. He divided the class into two groups. The control group received regular teaching/coaching techniques while the experimental group was shown a template of the optimal time/force curve of force exerted against the force plate embedded in the front foot block. In addition, the experimental subjects were shown their own time/force curve after each practice trial out on the field. Practice continued for ten days and trial measurements were recorded for all subjects throughout practice.

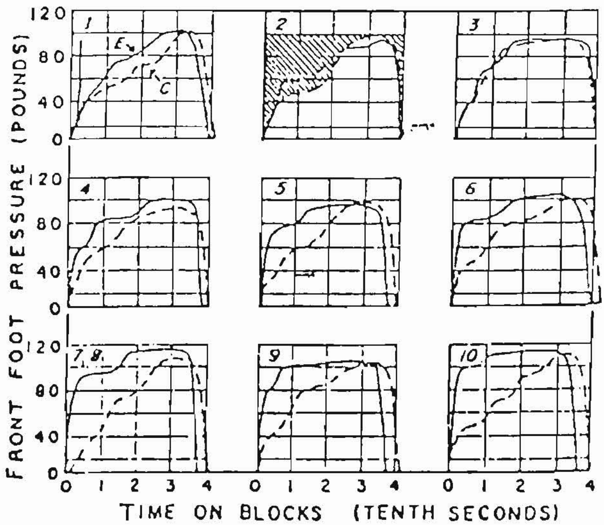


FIGURE 1. Day-by-Day Graphs of Average Force-Time Impulse.

HOWELL, 1956

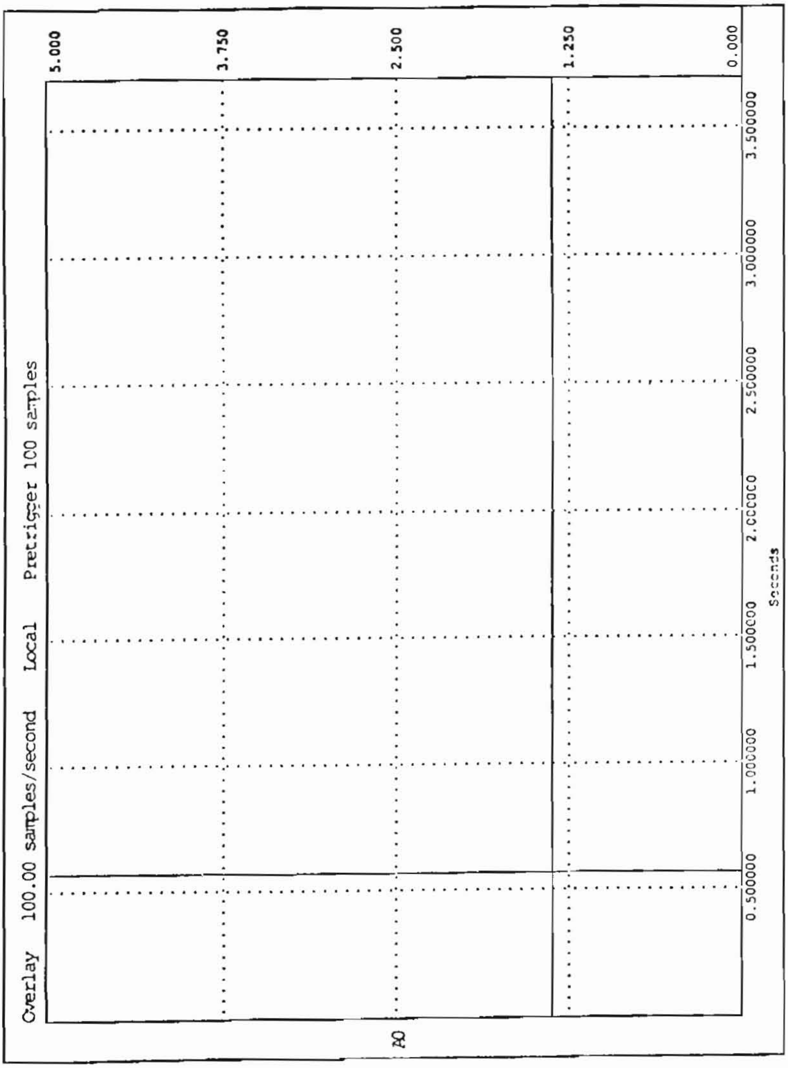
The results showed that those subjects who received visual time/force graphs were better able to closely approximate the optimal time/force output than were those subjects who only received verbal information feedback and instruction. Unfortunately, Howell did not report accompanying movement speed data so it is not known if the better time/force impulse resulted in better movement speed performance.

In a recent study in a different applied setting, Clarkson, James, Watkins and Foley (1986) wanted to determine if augmented feedback during barre exercises in a ballet class could reduce foot pronation. Beginning students wore a rather simple device - a pressure sensitive transducer and processing unit. The transducer was attached with tape to the plantar surface of the standing left foot. Pronation of the foot activated the transducer which gave an auditory signal to the dancer. At the same time a light emitting diode coupled to the unit, and optically to an event marker on a dynagraph, recorded the length of pronation time. The control group wore a bogus unit and did not receive any auditory feedback. All subjects were given typical reminders by the teacher to "lift your arches" just as is done in all dance classes.

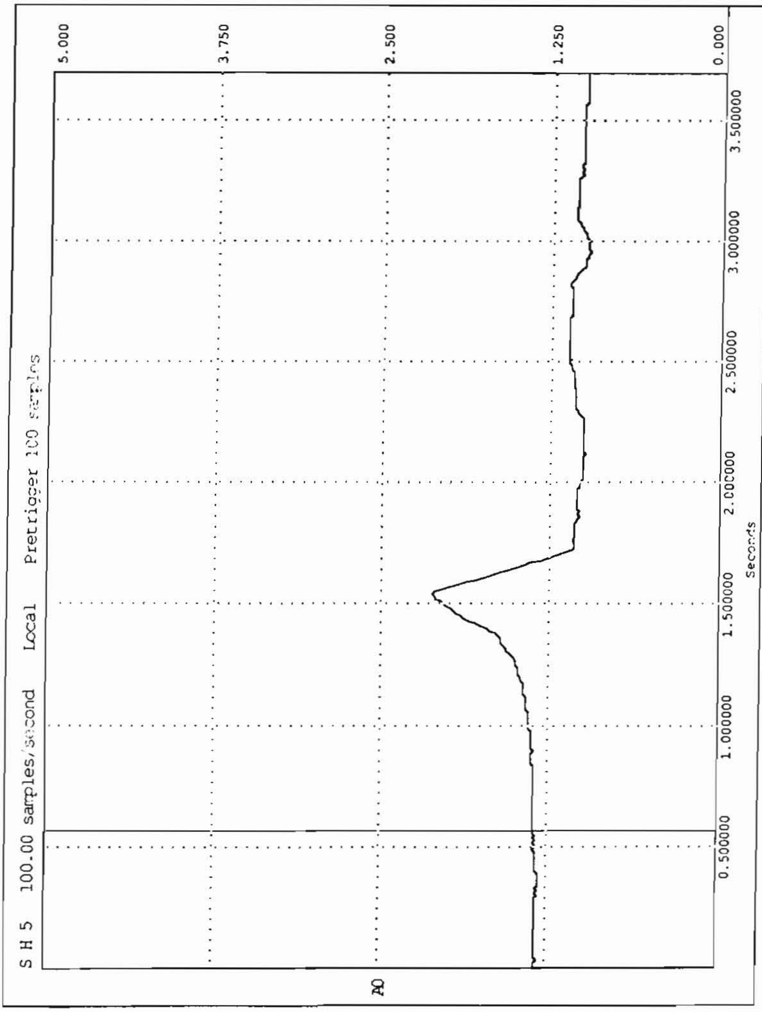
The results displayed the positive effectiveness of the auditory feedback from the transducer. The experimenters also used this same procedure with experienced dancers who displayed chronic foot pronation. The results were the same. Thus, not only did this type of feedback help beginners, but it clearly demonstrated that even after the experienced dancers were not wearing the unit, they displayed a decrease in foot pronation - learned changes in foot mechanics due to the type of augmented feedback they received.

One of my graduate students, Mike Butler, coaches private intermediate gymnastic teams made up of 13 & 14 year old girls. One of the problems he has in teaching moves on the uneven parallel bars is the inability of the girls to maintain straight knees when they do a specific move from the low bar to the high bar. They are so intent on not missing the bar that they flex their knees during the move. The judges, of course take off points for this problem. Mike decided to give these girls knee displacement information as feedback.

Testing his subjects in the gym, he attached a goinometer to the lateral aspect of the right knee and had it wired to an analog to digital converter interfaced with a Macintosh SE computer. In this way he could give instant knee displacement feedback to each girl. In addition, he attached to the screen of the computer, a model of what the graph should look like, in this case a straight line.



The subjects could then make a comparison. By placing the model over the tracing the girls could see what they should be doing and the magnitude of their error.

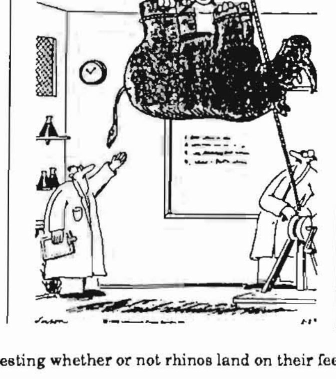


Unfortunately, the data are not completely analyzed, but it is obvious from a visual inspection of the graphs that those subjects who received this type of feedback decreased their knee flexion considerably compared with the girls who did not receive the feedback nor see the model. I believe this form of applied research has great potential and with the reduction in the computer costs has application potential in sports coaching.

Steve Freers is a karate expert, and one of the questions he has been interested in is how the person controls the karate kick differently when the target location is uncertain. As I understand it, the player knows prior to the movement how much relative force to exert, but the absolute target location is not known until the last instant.

Conclusion

In conclusion, I have attempted to demonstrate that through the use of biomechanical techniques, including the use of instrumentation such as film recordings, EMG, force plates, pressure sensitive transducers, goinometers, accelerators, and kinematic measurements, a more indepth understanding of how we control and learn movements is possible. Also, the information from these sources, in some instances, is a more powerful form of performance feedback than the traditional goal outcome results used to enhance learning. I believe the motor control experts and biomechanists need to work together in collaborative research efforts. These efforts can and should be in both the theoretical and applied settings. The opportunities for advancing knowledge and having an impact on how motor skills are learned and taught is enormous.



Testing whether or not rhinos land on their feet.

Finally, I ask you: "What is the question being asked by the biomechanist on the left?" "What is the question being asked by the motor control scientist on the right?" And what question did Gary Larson, the cartoonist, ask?

References

Clarkson, P.M., James, R., Watkins, A. & Foley, P. (1986). The effect of augmented feedback on foot pronation during barre exercise in dance. *Research Quarterly for Exercise and Sport*, 57, 33-40

Clark, J.E. and Phillips, S.J. (1987). The step cycle organization of infant walkers. *Journal of Motor Behavior*, 19, 4,421-433.

Guiard, Y. (1987). *Journal of Motor Behavior*, 19, 4 486-517.

Hatze, H. (1976). *Biomechanical aspects of a successful motion optimization.*

Howell, M.L. (1956). Use of force-time graphs for performance analysis in facilitating motor learning. *Research Quarterly*, 27, 1, 12-22.

Kelso, J.A.S., Southard, D.L. & Goodman, D. (1979). On the coordination of two-handed movements. *Journal of Experimental Psychology: Human Perception and Performance*, 5,2,229-238.

Lee, D.N. & Reddish, P.E. (1981). Plummeting gannets: a paradigm of ecological optics. *Nature*, 293, 293-294.

Newell, K.M. & Walter, C.B. (1981). Kinematic and kinetic parameters as information feedback in motor skill acquisition. *Journal of Human Movement Studies*, 7,235-254.

Mulder, T & Hulstijn, W. (1985). Sensory feedback in the learning of a novel motor task. *Journal of Motor Behavior*, 17,1,110-128.

Phillips, G.A. (1987). *Generalized motor programs and gait pattern analysis.* Master's Degree Thesis, California State University, Fullerton.

Sciaky, R., Lacquaniti, F., Terzuolo, C. & Soechting, T.F. (1987). A note on the kinematics of drawing movements in children. *Journal of Motor Behavior*, 19, 4,5;18-525.

Scully, D.M. (1986). Visual perception of technical execution and aesthetic quality in biological motion. *Human Movement Science*, 5, 185-206.

Weinberg, R.S. & Hunt, V.V. (1976). The interrelationships between anxiety, motor performance and electromyography. *Journal of Motor Behavior*, 8,3,219-224.