Varieties of Poling Experience

Dick Taylor

In a recent issue of the German *Nordic Sports Magazin* (2008) its editor Arnd Hemmersbach comments on the Norwegian summer ski festival in Kragerø. In the 100 meter sprint he obeserves, "Foremost, it was interesting to see the variety in the double-pole technique of these athletes, all of whom are world-class."(p.8) Many have noticed this variety, among them Ian Harvey the previous year in his article in *Master Skier*. Variability in human movement patterns has been observed more generally and analyzed for some years now by researchers from the point of view of systems-dynamic theory, with implications for our understanding and success with movement on skis.

One basic notion derives from the insight that movement variability is not only inherent in all biological systems, it is not to be viewed as a problem to be avoided but rather has a positive functional role in developing movement efficiency. In this regard random variability is distinguished from functional variability.

A second notion defines movement as the body's spontaneous and self-organizing responses to the environmental situations in which the movement takes place – terrain, speed, fitness level and skill, body build- without a normative pattern directed centrally from the brain. Since these situations are constantly varying, and no two movements are identical, it follows that movement variability is not only present *between* individual athletes but *within* each athlete as well. On the other hand, it is by the very means of such variability and substantial predictability in achieving efficient goal-movement is accomplished. In other words, the sensorimotor system works from the senses and environment ecologically backwards to the necessary interacting parts, that is, from the periphery in rather than from an executive center out.

These ideas have particular implications for skill learning and teaching. First, the movements cannot be deconstructed into discrete parts smaller than the full rhythm of the desired movement. Experiments with learning a volley ball serve two ways, for example, showed that if the toss was practiced alone, a different set of constraints came into play than if the whole serve was practiced. Learned separately, the toss was different than the toss in the whole serve, both in the shape of the movement and in its timing. Researchers concluded: "The constraints imposed on ball placement when the ball is tossed in isolation are quantitatively different from those present in the serve....The explanation is that manipulating task conditions in order to focus on a key element decouples the critical perception-action relationship that governs coordination in serving...For example, if the change effected by task decomposition is too great....the degree of interference determines the extent of the transfer, with significant changes possibly representing a fundamental shift to a coordination that is somewhat unrelated to that to be acquired." (MSV, 80ff.)

Research has also confirmed that "discrete and rhythmic movements constitute two distinct classes (an externally driven and an autonomous system, respectively) and that the discrete system is operational only in a limited range of temporal constraints."(*Sport and Exercise Physiology*, 2007, NASPSPA Supplement, 89f.) As counter-intuitive as it may seem, rhythmic whole-movements are more able to respond and adapt to higher velocities than discrete partial movements. Put another way, emphasis on a discrete partial movement may ultimately actually inhibit speed development.

In recognizing the potential problems inherent in confusing part for whole in human movement, we would do well to hearken to Stefan Lindinger's concerns with previous research approaches. He points out that there has been too little interest in “the swing components of the body parts for leg and poling push in the sense of qualitative consideration.” (Lindinger, 12) Topher Sabot's review of the recent USST clinic makes a similar point. (Fasterskier.com) Lindinger, following Schwirtz also echoes Hemmersbach's observation that there are various movement solutions among world-class skiers. (Lindinger, 41) And he emphasizes the environmental determinants of movement: “It is important to analyze the manner of velocity production also at the highest speeds because it is precisely here that significant changes occur. Misunderstandings can arise if we generalize the results of studies with limited velocity spectrums.” (Lindinger, 44) Other researchers advise attention to “more pronounced pendulum action of the swing leg in diagonal and better use of gravity forces as an addition to muscle power.” (Lindinger, 52)

It is useful to ask the question, therefore, not just whether but also why learning the power portion of a separate skill may produce a motion which is less than optimal for the movement as a whole. Research suggests it does. Along the way it will also become clear how so-called system-dynamic theories of motor movement overcome some of the limitations of traditional mechanistic/information processing models. I will refer often to Lindinger's skating review, *Biomechanische Analysen von Skatingtechniken im Skilanglauf* and to Jürgen Birklbauer's *Modelle der Motorik* (Models of Motor Learning). The translations are my own, and I will identify those sections by (Lindinger, page) and (Motorik, page). I will also refer to *Movement System Variability*, eds. Davids, Bennett, & Newell and identify the quotes with (MSV, page).

Along it has long seemed logical to understand complex movement by breaking it down into smaller parts, the limitations of doing so become apparent when one confronts the riddles of total movement through a variety of environments. A simple analogy is a chord of music, the subtle specific quality of which cannot be produced by practicing the individual notes. Indeed, the chord itself determines the manner in which the notes are touched in combination and interact with each other. This retroactive determination of the parts by the whole was first described by the Gestalt perception theorists in the period following 1908 in Germany. It reappears in this country in the 50's, in particular contrast to the dominant behaviorism of the times, then again in system-dynamic research of motor-movement theorist in the 1970's. It has profoundly influenced world-wide sports learning and teaching since.

The ways in which Gestalt perception theory comes to influence our understanding of movement begin to reveal themselves through a brief review. In complex systems, as in both perception and the movement patterns of organisms, ordering processes are assumed which do not have to either planned or internally represented but rather are determined by some few control processes. The laws of Gestalt formation are the same ones which play a role as system-immanent structuring principles in modern self-organization theories. (Motorik, 129)

Some of these principles are:

The Law of Good Gestalt (Whole-Form)...of Simplicity or Conciseness. Human perception tends to discover, and prefer, simple, concise forms. Kurt Koffka formulated it as follows:

"Psychological organization will always be as *good* as the prevailing conditions allow." The figural quality of units of perception will present the simplest and most memorable dynamic relationship. (Motorik, 125) Applied to movement, perception-action coupling, the idea begins to describe the organization of a sports technique.

The Law of Good Gestalt and Strategy Formation. This corresponds to the observation that movements with the same result often are carried out very differently, that is, one and the same performance can be realized by means of differing structures. "For example, less force can be at least partially compensated through more favorable lever relations, lesser skills through greater effort, a lower movement potential through better appplication or producing more favorable opportunities." In similar fashion we are able to produce equal movement performances through the combination of various parts of the body, muscle groups and joints (motor equivalence). The achievement of the same goal situation under differing conditions (equi-finality) distinguishes *living systems* from *physical systems*. (Motorik, 130)

It seems to me that this distinction is critical to our understanding of how we learn and teach technique. Our movement solutions will be organized according to our sense-perceptions of whole continuing movement through the environment, what is called perception-action coupling. Central to the dynamic efficiency of these movements in the **Law of Good Curve, or Continuing Line**. "One tends to place stimuli, or points which when combined are arranged in a straight line or gentle curve, into a relation which most strongly continues their previous direction." (Motorik, 126) An example would be the notion of "following the ski," which Marco Selle, Head Italian Coach and technique analyst, observes in top skiers, the tendency which combines balance and directionality.

Transferability and Individual Variance Formation. The quality of movement is demonstrated in that whole-structures, ex.relations of times, forces, parameters and sequences of their parts (relative timing, relative force application, sequencing) do not change within specific limits. (They posses invariance, Gestalt stability). (Motorik, 130) In other words, the body in motion organizes itself in dynamically stable ways, what we call technique.

Non-Summativity and Variability of Part and Whole. "The quality of a movement does not derive from its single components but rather from their prevailing relationship, that is, the total movement can have features....which are not to be deduced from the summation of the features of the parts.....Thus the coefficient of variability of the goal quantity in goal-oriented movements is in no way represented by the sum of the variabilities of the parts. In contrast to the much greater fluctuations of the parts, the whole is stable." Thus, the whole is not only more than the sum of the parts, it is different than the sum of the parts. "On the other hand, if the variability limits of the movements of the individual parts are even slightly exceeded, a break down of the total movement may take place. The whole is fundamentally more sensitive in contrast to the influence of the parts. In accordance with the principle *small cause-large* effect,....qualitatively new orders of coordination can come about through minimal shifts of system elements. (Motorik, 130f.) We have experienced such transitions in skiing, made a "change of gears" to another order of coordination, another technique, diagonal to kick-double-pole, V1 to V2.

Interaction Between Part and Whole. During the learning process the connection between the parts and the completion of the movement strengthens and becomes more differentiated. At the same time the correlation between part and whole sinks as the expression of the increasing independence of the whole from the parts. (Motorik, 131) In other words, technique becomes one movement.

Figure-Ground Relationship. In general the figure-ground relationship describes how the features of parts and Gestalt [whole-form, figure] are dependent on the prevailing context or relational system (ground) in which they exist....Problems arise for the attentiveness in the execution of a movement, for individual perception, and not the least for the origin of mistakes, if the context is inadequately determined....if no sufficient differentiation (contrast) is given....and if the figure-ground relationship is flexible.(Motorik, 131)

It is not difficult to see from these principles how modern system-dynamic theory contrasts with more mechanistic classical learning theory in asserting that (1) the quality of movement does not derive from its single movements. (2) It also notes that “the concept that free interaction leads to order contradicts the mechanistic theory according to which order can only be achieved through external force arrangement.” The idea that there is a single optimal poling arrangement for all environmental conditions (speed, terrain, fitness level) suggest to me an example of the mechanistic discrete partial movement approach, as one coach hopefully suggested, “an American double-pole,” within what is perceived as a relatively limited optimal range of power.

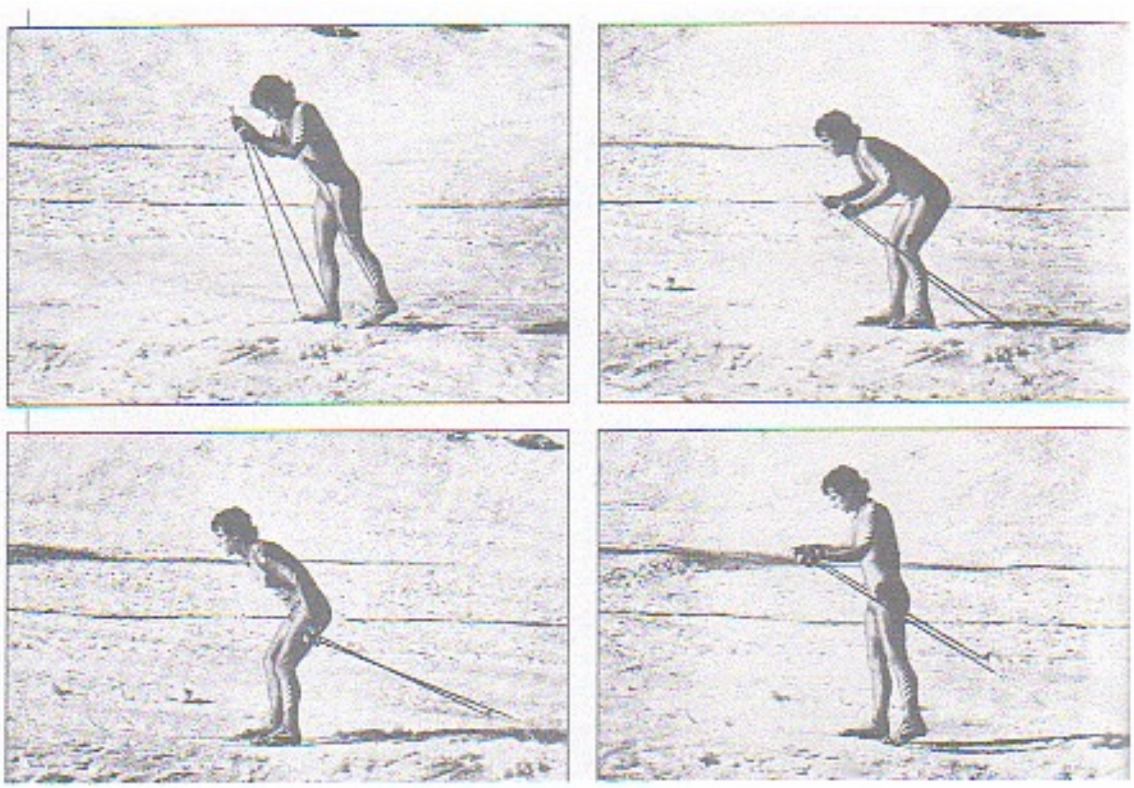
This also strikes me as being in line with classical learning theories which emphasize (1) the ingraining of movements, (2) the importance of mistakes – their being something to be avoided, and (3) the importance of ideal or normative goal techniques.

One key concept in getting beyond mechanistic ideas is **variability**. A related concept is the **spontaneous self-organization of the body toward optimal movement solutions**. A critical discovery of system-dynamic research has been that there is measurably greater variability in the segments of a movement than in the variability of the movement as a whole. This is precisely because “the whole is substantially more sensitive compared with the influence of the parts. According to the principle small cause-large effect, minimal fluctuations of system elements can produce qualitatively new conditions of order.” (Motorik, 131) In the complex dynamic of movement solutions the subtlest of spontaneous adjustments can have a dramatic effect.

Any skier has experienced that, as well as its opposite: selectively elevating the power application of one segment can have a very small effect. Take an example from cutting firewood with a buck saw. If the saw binds, you can either apply drastically more force, or you can minutely adjust the plane, pitch or lay of the saw and proceed more easily and efficiently along. As one researcher explains it, this phenomenon is not “constancy elevated to rigidity but rather more purposeful interactive adaptation of the parts to reaching a goal. Variability is not a factor of mistake but the necessary element of final stability.” (Motorik, 134) Variability and the sensorimotors systems' natural impulse to self-organize the body's adaptive responses to environmental variants [or constraints] are what ultimately produce the most efficient movements, with an almost infinite repertoire. In fact, “at a certain level the variability of the segments/parts appear to gain increasingly functional meaning for the stability of the movement result. This observation stands in clear accord with Berstein's second stage of coordinative release (from freezing to freeing).”(Motorik, 136)

When I watch the “new double-pole,” I often see frozen movement. It should be one of a very flexible store of variants, and not group variants only but specifically intra-individual variants. (Lindinger has clearly understood the new approach, as have most Europeans). Zach Caldwell' review

(NENSA Bulletin, Nov., '08) of double-poling variants and the recent evolution in double-poling technique is also a case in point. Evolution does indeed produce variants, and one ought to remember as well that the latest variant can equally represent chance as well as progress, as is the case with evolution in general. A chance that works well for one skier could as well equally depend upon other capacities of that skier. The whole range of variants over the years is itself an example of the variety of movement solutions skiers and coaches have come up with, a catalog of which top skiers use in the present, as they have throughout the past. One example is Dan Simoneau's article in *Cross-Country Skier*, Nov. 1985, p. 18, entitled "Power Double Poling."



The way Dan describes it in 1985 sounds pretty much like the "new" double-pole of the last few years, but in a broader perspective.

"This new technique is an abbreviated version of the full double-pole.... In the power double-pole you stop the follow through of your hands at about your hips. The motion is shorter, choppier than a full double-pole. You sacrifice the power of a full compression because in certain situations it'd more important to keep momentum. You do this by poling faster.

Maintain the basic components of the full double-pole, however. Keep your weight forward and over your poles. Keep your hands in tight under your shoulders. In this position your trunk muscles will help you along. This is why power double-pole is a powerful stroke.

You might recover quickly after each stroke because once you stop pushing on the poles, you start to decelerate. Quickly reach again with the arms and upper body to keep our momentum....Your form need not be perfect. Concentrate instead on quick recovery, but if you're getting little or no push, you've shortened the motion too much....

[After some hard, uphill double-poling] Then move to the flats or a gradual downhill and do some full double-poling. This is the time to concentrate on form and the full range of motion. It will reinforce the basics and keep your full double-pole motion sharp. After all, you won't be able to power double-pole all the time."

Another way to an understanding of the system-dynamic approach is through the **concept of causality:** How is a change in movement pattern caused? From the perspective of the mechanistic (Newtonian physics) model and linear causality an increase in force application results in an increase in movement efficiency, in our case skiing speed. But we have seen above that often a very small change begets a very large effect and vice versa. This non-linearity is characteristic of complex biological systems. We also know it from the history of Americans' study of skiing. Charles Dilman's studies of classical technique in the late 70's suggested that stride length was what resulted in higher skiing speeds. It did not take long, however, to realize that this confused cause and effect: it was speed which caused longer stride length. Both conclusions suffer from linear thinking. System-dynamic thinking would lead to a better explanation: stride length and speed are mutually interactive and interdependent and are each variable with respect to the environment in which they take place, both the external natural environment and the individual internal enviroment of the athlete. Their dynamic relationship is not so much sequential as it is simultaneous. Certainly it is spontaneous and not mediated by thought.

Finally, non-linear (circular) causality can explain the qualitative changes in poling when with increasing speed it goes from the more pushing, shorter radius pumping during acceleration phases to a more pulling, "grasping space"(German and Russian term) movement during higher velocity phases. Once again, the ultimate optimal movement will be variable with respect to terrain and fitness level, as well as with respect to whether the skier finds him-/herself in an acceleration/power phase or in a speed maintenance/extension phase. Even sprinters, on foot or on skis, spontaneously adapt their movements in these varying situations. Given the wide variety of skiers, in age, proficiency, fitness and body type, it is not surprising that analysts observe variances in the technique applied. The key for athletes and coaches, therefore, is not to get stuck in over-prescribing a single preferred movement solution to the multitude of situations, that multitude which is the very essence of the sport. Speed ultimately is the result of freedom of movement, not control, even though control may be more comforting emotionally for both coach and athlete.

That said, there are more general optimal patterns of human coordination which can be identified toward which successful athletes tend, a number of essential "control processes." A comparative review of the different approaches to learning and teaching movement skills to athletes can be helpful.

"A system-dynamic oriented movement science reflects human movement as a complex system on the basis of its order development (coordination patter). A stable order condition of the motor system appears in the form of a high movement stability. The contradiction unit of stability and variability as a central problem of motor movement research is taken into consideration in the various system-dynamic models. Their analyses apply foremost to complex performance as a whole and not to its dissection into individual parts," (Motorik, 118) as the review of Gestalt principles has already described.

Other conclusion arise: stability and variability of goal movement will not be seen as a contradiction. Stability is achieved through variability, not by removing it, as we will see. Just one reason for this is that the complexity of human movement itself defies mechanical simplification. It has been calculated that the number of muscles activated in order to execute a Fosbury Flop in high jumping is 10 cubed. The essential starting point for system-dynamic movement analysis, and admission of the real challenge, is that "every natural organism is characterized by being at all of its – in principle innumerable – organization levels irreducibly complex." (Paslack in Motorik, 118) This is one of the reasons analysis cannot be dissected or isolated into individual parts. Any discussion of poling, for example, cannot end with maximizing a push measured at a single or small velocity range, and certainly not by a mechanical demonstration while standing still. Nor can movement complexity be overcome simply by ignoring it in favor of a simpler and more convenient mechanical solution. (A daughter-in-law with a lower leg prosthesis has endured a further loss of mobility with that approach.) Laboratory analysis will always produce some data and measurement, but if the environment of the movement is radically stabilized or simplified in order to isolate the particular movement to be analyzed, then the measurement will reflect the capacities of the measuring device, and the bias of the analyst, more than the capacities of the athlete being measured.

Daniel Levitin describes the problem further. "This underscores an ongoing problem that plagues all empirical science: the tension between rigorous experimental control and real-world situations. The trade-off is that in achieving the one, there is often a compromise of the other. The scientific method requires that we control all possible variables in order to be able to draw firm conclusions about the phenomenon under study. Yet such control often creates stimuli or conditions that would never be encountered in the real world, situations that are so far removed from the real world as not even to be valid." (*This is Your Brain on Music*, 2006, p.140) It should be obvious that isolation of parts of movements experimentally, particularly in light of the fact that movement is so real-environment sensitive, can only result in limited, if not doubtful, technique prescriptions, as recent system-dynamic study has shown.

A contrast in the approaches is clear. "In the classic system theory the dynamic perspective is differentiated from the stationary or static systems initiative. The latter concerns itself with the analysis of systems in a quasi-stable state; it investigates relationships which come about when the system is largely in balance, that is, it has time enough to come to rest. The dynamic-system analysis, on the contrary, asks about the transient processes, it concentrates on the transition phases between the [resting] states." (Motorik, 116f.) In traditional analyses "transitions between the states have often been considered to derive from the states themselves....In other words, it was assumed that changes between the states could be understood in terms of the characteristics of stable states." (MSV, 38) But "a theory of postural transitions [for example] based solely on mechanical factors would be inadequate....because there is not a one-to-one correspondence between mechanical properties and patterns of posture control. A given set of mechanical properties can give rise to more than one coordination mode. Conversely, different types of mechanical properties can give rise to a single coordination mode." (MSV, 39)

A good example of where transitions and control properties are critical is music. Sharing my obeservations of how her master piano students with such gracefully differentiation and power got onto each note and then off, and how they moved from note to note, Tamara Produbnaya remarked, "Yes, they are just like your athletes. The mechanics are only the beginning; how they get to the bottom of a tone and express the phrase takes years, a grasp and feel for the whole music."

Any such biomechanical task, because it is determined by movement, is also mediated, to be sure, by the intention/perception of the athlete. As with music, the athlete's perception itself is not passive. It is a process in which an exchange of information is taking place, in which movement is not isolated but perceived in its contextual function. The American scholar Kelso (1997)(Motorik, 165) puts is clearly: “The point is that context is everything. Remove context and meaning goes with it.” Gibson (1996) (Motorik, 119) accentuated this environmental aspect of movement and “arrives at a radically peripheralistic view, in which control and steering do not originate from the brain but from information which the human being through his self-perception received within the environment.” (Motorik, 120) Given multi-dimensional starting conditions and movement results in varying terrain as continuously changing speeds, the construction of invariant patterns of movement/technique thus makes little sense.

An example of what happens when this principle is missed might be a report from a recent USST clinic in which a rationale for a manner of double-poling was presented. One partner drill “emphasized proper hand position – one person resisted while the other 'poled' down with extended arms (weak position, easily resisted), then switching to 'pole' down led by the elbows (elbows 90 degrees or less, hands compact to the body, motion initiated with a crunch, difficult to resist). The difference was extreme – my partner could hold my hands relatively stable as I pushed with straight arms. Switching to proper technique resulted in easily blasting through the resistance.” (Sabot, Oct. 15)

Quite apart from the question whether poling is initiated by a pull rather than a push, what is missing in this demonstration is precisely the context – movement itself and speed, not to mention the internal environment each athlete is. Unfortunately, the NENSA/Andy Newell technique CD repeats this demonstration, even though his own poling shows a more flexible range of poling movements. Jakob Waser, a researcher with the Swiss Federal Institute of Technology, analyzed the variances in poling and leg movements among skiers achieving similar speeds as early as 1982. His article appeared in *SKI COACH* in May, 1983, p.2ff. As a review of photos showed, the structure and quality of poling varies quite dramatically and is thoroughly context-sensitive. As I have already suggested, poling also progressively transforms from a movement which is only initially pushing to one which is predominantly pulling, and once any speed is present one which begins with a pulling force and follows with a lower force push. In any case the duration of the poling is very short.

A number of poling analysts in past years have also made the point that poling in part becomes effective because of the longer time poles allow for the application of force. That this belief contradicts the well-established principle that speed in *inversely* proportional to the time of force application is not noticed. That Waser documents the principle in poling as well as kicking (as have others in other sports) as early as 1982 points out the folly of not remaining attentive to available sports scholarship. As more modern grasp of the principles of movement would also makes us wary of part-for-whole confusions. Thus we would not conclude that because the time of application shortens with increasing speed that the movement in its range should shorten as well. The movement rather simply completes its optimal natural range in a shorter time. This discussion often arises when the notion of “follow-through” is debated.

It is also for its different context that research done on roller skis is at best approximate to snow skiing. The fundamentally different purchase the pole picks have on asphalt as compared with snow clearly results is different poling possibilities. Eldar Rønning and Frode Estil roller skiing in the summer at the Saku Suverull fest in Estonia move differently than they do at Oberstdorf in the winter. In either context no prescription for poling can be optimal without consideration of ballistic, elastic whole-body movements on weighting and unweighting the skis and the patterns of velocity modulation between skis and the glide pattern of each ski. (Charles Dillman and Janet Dufek analyzed this difference rather thoroughly in another article in *SKI COACH* in August, 1983, p. 4ff.) In the professional world of coaching, inattention to past research is not permissible. If we presume to speak or write with integrity, not to mention teach, we must take past research into account, proving it useful or someway in error by means of scientific testing. Thus poling prescriptions based on roller board measurements or roller skis are anything but definitive for optimal movement on skis. Charlotte Kalla made this very point on the Swedish cross-country website this past October (2010).

The report of the USST clinic mentioned also gives an example of the question about how effective movement is reliably learned. “The coaches emphasized that in general it can be good to isolate different parts of the body when working on technique. - focus on either legs/lower body or the arms/upper body. Don't try to do everything at once.” We have all proceeded in this manner at one time or another, and with some success. But let's also entertain the topic a little further.

Recent system-dynamic research into whole-movements discusses the topic in a manner useful to coaches. “The dilemma of whether complex motor skills should be broken into smaller parts or left as a whole for the purpose of practice has been one of the most enduring for those studying the acquisition of movement skills. Unfortunately, meaningful theoretical guidance has not been forthcoming and there have been few direct examinations of the topic with little support for the prediction that part practice regimes have positive transfer qualities.” The teaching approach to this dilemma has largely been based upon subjective assessment of “appropriate units of action” and the “instructors knowledge of the skill itself.” More critically, in my view, is this: “Clearly the success of this approach rests on the assumption that the key factors that influence the dynamics of a skill are known *a priori*.” Newell summarizes the problem by saying current teaching practices are “not founded on strong evidence and theoretical interpretations of their effects are even more hazardous.” (MSV, 80).

My hesitation to isolate double-poling from the swing phase of the complete movement cycle extends to isolating double-poling from kick-double-poling. I see skiers kick-double-poling faster but still poling with a short radius, or not kick-double-poling at all on the assumption, apparently, that double-poling alone must be faster, or more efficient, because the rate of turnover is higher. Though the rate of turnover may be higher, however, the working velocity of the individual stroke may be slower. Only actual measurement at the various speeds can inform the individual what solution is the best, and the solution will vary from skier to skier. Momentary visual observation is simply too deceiving. One movement used through a broad range of velocities may in fact reach its terminal effectiveness too soon.

Back at the wood shed, you have a favorite splitting axe. It could be a heavy head with a short handle which you can simply drop in front of you, or a light head with a long handle which swings through a longer range easily and splits as well with speed rather than weight. Thus the options for the skier, except the moving skier needs the longer, faster handle to stay ahead of his own speed.

These concerns can be traced back to a shift in the way researchers looked at motor movement beginning in the late 70's, tough the antecedents of the newer model, as I have noted, were much earlier in the century. The shift can best be described as a new-found basis for recognizing the limitations of top-down, hierarchical models of motor movement. These models were mechanistic in the nature, in the sense of steering mechanisms directed from a cognitive central brain executive, as with the computer model for information processing. Cause and effect were seen in linear relationship (more force-greater speed), in an environment which was essentially neutral, if not adversarial, the human being the sole determining agent of the movement. Even movement itself as an environment was not considered decisive to the dynamic. As with an automobile, you worked the machine according to its mechanical set up; what the road did was not really significant. Whatever the case, the point was that the driver/brain was in charge, and the less noise and vibration the machine made the better. Individual parts could be isolated, improved or replaced.

Two people in particular are seen as the originators of the new, so-called system-dynamic approach: Nikolai Bernstein, the Russian neurophysiologist and biomechanist, and James J. Gibson, the founder of ecological perception psychology. Their initiatives were in turn rooted in the Gestalt psychology/perception theory of the early century. It is worth investigating a little further both for its content and for how early it began, and for how long it has been both known in Europe and unknown here, certainly in ski circles at least.

It was his recognition of the inherent variability in movement that lead Bernstein to his notion of **degrees of freedom**.

"The problem of the degree of freedom (Degrees of Freedom Problem) formulated by Bernstein (1975) serves as the central theme. The execution of a specific motor task makes it necessary to chose from among the numerous solution possibilities which are available to our motor system, and thence to coordinate the superfluous degrees of freedom in the movement apparatus. It is in this manner that Bernstein understands as a totality/whole the manner in which the superfluous degree of freedom of the moving organism is overcome."(Motorik, 119) This coordination is accomplished in three stages of progressive skill development. 1. Freezing: fixation/fassening down superfluous degrees of freedom. The movement at this stage is thus angular and awkward, the body position and imitation tensed, the breath constrained. 2. Freeing: loosening, the first stage of freeing up coordination. The artificial fixing of the degree of freedom, which in novices can be observed in the form of tensed restraint, loosens. Still, in this transition stage the central nervous system is overburdened by necessary attentiveness, and movements (extra movements) which are angular (many angled), less effective and unnecessary arise. 3. Optimal use of reactive phenomena (second stage of freeing up coordination). This is the highest level of coordination "where the organism no longer fears the reactive phenomena which appear in the system....but rather where it is in a position to build up a movement in which the reactive phenomena which are encountered are maximally made use of," that is, the mechanically reactive forces – a sort of rebound forces which arise from the muscles elastic features – are utilized in a positive way. Bernstein describes these movements as being *dynamically stable*. (Motorik, 146ff.)

In his ecological initiative of direct perception, Gibson (1986) advocated a naturalistic understanding of the individual-environment/surrounding-world connection, since motor actions always take place in a confrontation with the surroundings....In accentuating the environmental component Gibson arrives at a radically peripheralistic view in which control and steering do nt originate from the brain but from information which the human being through his self-perception receives within the environment. (Motorik, 120) Thus, the context of movement is not simply acted upon, it interacts with the moving human and co-determines the movement qualities. The human's movements are simultaneously actions and responses, since the human environment and the natural flow into each other. Technique is then not only what we do but how our bodies respond to the movement and its encompassing environments by themselves. Bernstein ultimately formulated this relationship somewhat less radically than Gibson, emphasizing rather the ambiguity of center and periphery. [Cf. p.6: The relation is not cause and effect but simultaneous, i.e. self-organizing.]

Gibson's determination that whole-movement forms decisively in interaction with its surroundings, might even, in a manner of speaking, “become” them, includes Bernsteins view of living movements in a biodynamic web. (Motorik, 148) “The whole-character of this way of seeing things is expressed in his view that movements are not described as a chain of details but rather as a structure subdivided into details. The whole-structure possesses at the same time a high differentiation of its elements and the different elective interactions between them. Thus the change of a detail....can draw a series of other modifications with it....that is, the effect must not necessarily be proportional to the cause; a small cause, for example, can have a large effect. The movement never changes due to the influence of a detail through the change of a detail. It responds to the change of every tiny unit as a whole, in which case very clear changes in such parts occur which are far afield from the primarily change detail sometimes in both space and time.” (Motorik, 148, Bernstein, 1975) How often have we coaches improved the timing of the feet by means of an adjustment of the hand!

With practical coaching in mind, Schöllhorn (1996) interprets the linear understanding of causality, derived predominantly from the observation of mechanical bodies, as the basis for additively constructed training models. (Motorik, 218) A sequential training of the individual elements of a movement does not have to lead perforce to the desired goal movement, which can be recognized by considering that often a *greater* effort achieves minimal changes, while *small* instructions of training exercises at the right point in time bring about an entirely different movement result.

Schöllhorn is the founder of a new teaching paradigm called **differential learning** which has been widely practiced in Europe in recent years. By inserting a range of variant movements and movement qualities (ex. Tensed-relaxed) into practices, and varying the times of insertion, the athlete is provided both an open feel for his possibilities and a stronger sense for the contrasts between the possible movement solutions. His self-organizing choices thus become more sure (perception-action coupling) and more flexible (environment-responsive), and, as Schöllhorn found out, improvement was both more rapid and more enduring.

Despite the positive functional role now assigned to variability, it is critical to point out that movement stability remains the goal. The goal of the whole process is to achieve goal-directed order. That is the key to performance. Thus when we notice differences in the technique of world-class skiers, that should not lead us to conclude that there are no generally determining structures of movement at all. The intense concern with technique by both coaches and athletes in Europe affirms that although individual variants are taken for granted, there are similarities in patterns of coordination which are found in those who succeed. The key word is **pattern**, that is, a pattern of varying movement dependent, as I have noted already, on the spontaneous responses of the human athlete to interaction with the environment (speed, terrain, fitness). The pattern is multi-dimensional and defines the optimal dynamic shape of the athlete's movements and provides the optimal movement strategy. The variants inherent in optimal patterns of technique (order of coordination, “attractors”) are no longer random, haphazard, or totally individual. Rather they represent particularly functional human body variants which progressively define “good technique,” effective movement solutions. The determining biomechanical environment from which these patterns derive and are executed is dominated by the principles of gravity/balance and speed, more specifically **directional balance** on the moving ski. And since balance is sustained in gravity by being vertical to the point of support on the ground, the swing phase of the poling (which includes body/shoulder mass) lifts in the direction of the gliding ski. Think also of a gymnast on the balance beam: arms are held perpendicular to the line of the beam as is the shoulder axis, and move parallel to it.

In this regard, it is interesting to see how skaters have added a refinement in sifting the initial balance “platform” from slightly inside as Lindinger suggests in his study) to more dynamically stabilized by landing initially slightly outside the ski. (For description's sake I call it “over-shifting). The weight transfer to the next ski thus can begin and end on a flatter, and thus freer, ski.

Miriam Goessner

In describing how Pietro Piller-Cottrer (s. photo sequences at end of article) accomplishes this, Marco Selle, Head Italian Coach and technique commentator for the German *Nordic Sports Magazin*, states: “This narrow steering demonstrates good control of the ski, a dynamic center of mass, economy in the movement and a fine balance and coordination.” And it not with Selle alone that one hears echoes of system-dynamic movement vocabulary among European and Scandinavian coaches. That is in itself not surprising, considering that the theory has been current since the late 70's. It also follows from basic movement theory that, as Selle notes about Piller-Cottrer's technique: "The shoulders are always oriented to the direction of the ski tips."(p.36) He also contrasts Piller-Cottrer's "deeper" classic double-pole with shallower marathon double-poling, suggesting yet another variant among skiers is different racing environments.

With this variability in mind, it is not surprising that research into optimal pole lengths for various skiers and types of skiing, in different terrain, has shown shown significant differences between individual skiers not only based on level of technical skill and fitness (Lindinger, 80) but also personal preference – Selle notes Piller-Cottrer uses a somewhat long pole in classic, Majdic a shorter pole, too short in Selle's view.

Another example of how variability of movement segments actually contributes to the stability of the goal skill is pistol shooting. "It was found that compensatory movements of the arms enabled skilled marksmen to reduce the variability in the spatial orientation of the barrel. In contrast, novice marksmen were unable to demonstrate such compensatory movements and therefore exhibited greater variability in the spatial orientation of the pistol barrel." (MSV, 51) Biathlon skiers doubtless could describe this phenomenon for us.

The point is that variability in the movement segments is functional, a source of information feedback and feed forward (MSV, 29), not a mistake, in reacing stable goal movement, as I described in my example of sawing wood. What we see in top skiers is that constantly minute adjusting variability, which *frees* them to stable movement patterns. This how human dynamic-system movement takes place.

The editors explain further. "In dynamic-system theory, patterns of coordination emerge through generic processes of physical self-organization rather than being prescribed by some sort of executive regulating agent (Kelso, 1995) or rigid technical norm. As early as 1975 Bernstein recognized "that the not-to-be-influenced dynamic pf the surrounding/environment stands in decisive contradiction to any sort of available possibility of imprinting the brain with standardized motor formulas."(Motorik, 428)
With this in mind, the long-debated distinction between technique and style can be laid to rest, for as Bernstein also logically concluded: "For every human being there exists for every movement task, and based on the biodynamics of the body build, only one dynamically stable form through which the subject has learned to utilize reactive forces optimally....these dynamically stable forms approximate what we call *movement style*." (Motorik, 428) At the ultimate level of movement mastery style is each athlete's particular optimal technique. We hasten to add, however, that style/technique is not a haphazard phenomenon: "because each person poesses his or her 'signature,' it makes little sense to average performance among individuals...This does not mean that putative laws and principles of learning cannot be generalized across individuals; laws wouldn't qualify as laws if it were not possible to do so. It only means that the law is instantiated is specific to the individual." (MSV, 136)

"A research strategy for proponents of dynamic-systems theory has, therefore, been to identify observable low-dimensional macroscopic variable – the so-called order parameters - that define stable and reproducible relationships occurring among the components of the sensorimotor system as it searches for and adopts functionally preferred states of coordination, or attractor states....When the sensorimotor system adopts a functionally preferred state of coordination, the dynamics of order parameters are highly ordered and stable, reflecting the capacity of the sensorimotor system to produce consistent patterns of coordination. It has also been shown that variability in the dynamics of order parameters, exemplified by fluctuations in stability, reflects the capacity for flexible and adaptive sensorimotor behavior, thus enabling patterns of coordination to be tailored to the specific environmental and task demands." (MSV, 51f.) *What we call the essential elements of technique and tactics are clearly what are being described here.*

"When dynamic-systems theory is applied to biomechanics, greater emphasis is directed toward analyzing actual patterns of movement, instead of discrete cinematic measurements, as they provide a window into the underlying dynamics of the sensorimotor system."(MSV, 57) *This suggests to me the need to analyze, and teach, the whole pattern of poling, not just the push part.*

If we need further convincing, the example of swimming might suggest to us how we might better access the dynamic nature of skiing movements. " To examine the functional role of movement variability, we examine the different strategies that might be used by swimmers to maintain optimum efficiency and effectiveness in relation to key performance constraints. We specifically focus on the effect of swimming speed on emerging patterns of coordination....From the perspective of dynamic-system theory, any variability in movement patterns could be interpreted as reflecting the conscious or unconscious attempt to satisfy, in the best way possible, the unique confluence of constraints impinging on the swimmer – a process referred to as self-organizing optimality by Newell (1986). (MSV, 59f.)

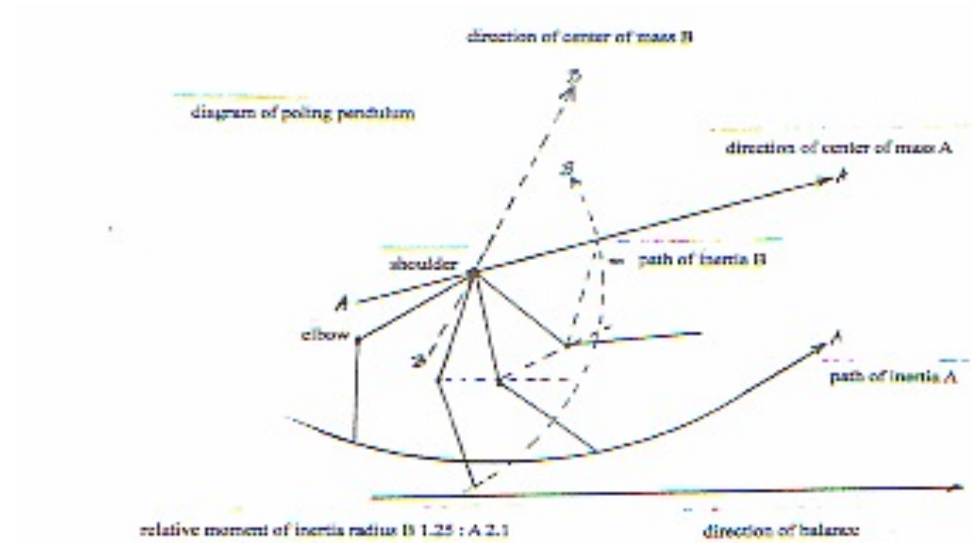
"Despite the clear need to understand how patterns of coordination are modified during a performance, this aspect of performance has rarely been examined in the literature. The main reason for the lack of research attention appears to originate from the fact that most scientific investigations...have tended to adopt a reductionist approach and examine those descriptive stroke characteristics that are readily observable from the pool deck such as swimming speed, stroke length, and stroke frequency, rather than the actual patterns of coordination that produced them....Small-scale adjustments to the orientation of the hand based on changes in the 'feel' of the water may be made *prospectively* in skilled swimmers because of the tight coupling between perception and movement sub-systems. However, large-scale changes in whole-body patterns of coordination may be necessary to maintain optimal efficiency and effectiveness, particularly with the concurrent increase in resistive drag forces experienced by the swimmer. It is feasible that a non-equilibrium phase transition or bifurcation characterized by a shift from one state of coordination to another by the swimmer may occur."(MSV, 60f.) Examples given are human gait, equine gait, swimming motions in marine animals, and I would of course include skiing "gaits," V1 to V2 to V2 alternate, diagonal to double-pole-kick to double-pole. And these are just the "front sprockets," with variants for each, the "rear sprockets" For American skiers the top end of the speed spectrum has presented the greatest challenge, and it is where mechanical solutions may particularly fall short, and Lindinger suggests (Lindinger, 44) The authors of Movement System Variability state the problem as follows; "With the theoretical possibility of phase transitions and new attractor states [patterns of coordination, i.e. techniques] emerging during swimming, and with the lack of previous research, it is unclear whether swimmers are training under appropriate task constraints by swimming at speeds lower than those habitually used in competition......However, sports scientists and practitioners should remain tolerant of functional variability shown by swimmers in emergent adaptations to basic coordination patterns of aquatic gait owing to the interaction of organismic, environmental, and task constraints."(MSV, 62)

What can this suggest to us about optimal poling and how to teach it?

First, examine the *entire poling phase rhythm* from *the perspective of its environment*. The optimal radius of the swing forward and of the application of force down and back will effectively be determined by speed, terrain, and athlete fitness. Any attempt to allow one relatively invariant movement pattern to dominate throughout all speeds and terrain and all athletes will neglect fundamental movement possibilities. Let them all happen! As the speed increases, the radius must length to continue "grasping space" at that speed. Less force is necessary but also greater speed of application, and that speed of application generates the right force per unit of time. The force cannot be applied like punching a pencil through a piece of paper, or stabbing the ground near your foot because the ground is moving toward you too rapidly to accept the force before it has passed beneath you and is gone. Here Heikki Rusko's reminder is relevant: "Most good skiers eventually have enough power, what they lack is the ability to apply is rapidly enough." (*IOC Book of Cross-Country Skiing*)

Examine the free kinetic force of the swing phase. It starts, sprints, and climbs, the tempo is high and the acceleration paramount. In that case the radius of the swing phase, and the moment of inertia is kept naturally smaller. The is simply not enough time to lengthen, and reducing the moment of inertia "lightens" the arm/shoulder. That is the natural movement response. At the top end of the speed the radius lengthens, like a pitcher reaching back before firing a fast ball, with stretch-shortening cycle, for the body "knows" that greater speed is developed, and maintained, by a longer pendulum radius. Watch any skilled young scooter rider or skate boarder. He will accelerate by pushing hard and short against the ground initially. But as the speed gets going, he will rise and take time to let his leg swing longer and more forward and strike the ground farther in front with a lighter, clawing, space-grasping, stroking motion initiated from the hamstrings.

Between these two extremes are virtually infinite variants But if at good speed the swing pendulum is broken upward at the elbow (like a broken baseball bat), even with a high upper arms, then the free initial force is largely canceled, or directed upward instead of "following" a momentarily unweighting ski. The ballistic momentum of the upper body is also lessened if it is held too upright, the hands held close in. That might be effective if you are climbing a ladder. As the velocity increases, however, the flow is moving faster forward than the tightening up-curve of the swing phase(s. diagram) Relative to the dynamic directional balance of the moving ski, and the center of mass rotation of the center of mass over the ball of the flexing foot, a break upward in the forearm produces a moment of inertia diverging from the direction of flow.



What we do see is a progression of responses to speed, a change of orders of coordination, when the poling begins at slower speeds as a push-off a short arm/shoulder, closer to the body, then ultimately expands to a pull, as if the arms/poles fixed a sort of sling shot in the ground through which the body is fired on elastic bands, accompanied by a more complete downward acceleration of the upper body. I also see it somewhat like a kid on a swing set, arms essentially stable and the swing initiated with a pelvic tilt from the sacroiliac joint. Kayakers understand a related movement as "pulling the boat to the paddle." Swimmers are instructed to pull the body to the hand.

If this movement of the upper body does not follow the speed over (in other words, the arms are not bent toward the head/upper body but rather the head/upper body moves forward into the stable hands/poles, and that creates the elbow angle, whatever it is), even the center of mass elevated by the recovery swing of lifting arms, will add little to the motion because it remains too close to the body. The only way the center of mass can contribute to directional momentum is through the leverage gained by moving the shoulders forward over the ski to keep up with it, like a rider leaning forward to keep up with his galloping horse. (Waser describes this already in his 1983 article, as do sports biomechanists in general.) It then can function as the higher located axis, actually in front of the body, over which the body levers as a whole, adding weight to the poles to stabilize them, and raising the hips behind, which in turns simultaneously creates space for the recovering swing leg to move through with a longer radius and thus greater moment of inertia, free energy at the top end of the speed.

What we are really asking about the arms is: How do they work? Or: Why do they work the way they do? First, How do they come? Two ways: elbows bent and lying approximately 45 degrees to the direction of glide. Two results: even when "extended" they are bent, and even bent they will retain a certain "stiffness." I use "stiffness" in the biomechanical sense that muscles respond to ground contact forces with varying degrees of stiffness/resistance to flexion in order to convert those forces into an optimal rebound/lift, and example of self-organization and natural preflex. In any case, the operant measure is the radius of the pendulum between hand and shoulder, or more precisely, from hand to the center of the back.

And why do the elbows rise up and to the outside with some skiers, along with the shoulders? Partly, again, that is how we are built. Partly that gives the chest more breathing room, much as a singer holds his arms. For the skier it elevates the arm/shoulder lever and improves the mechanical advantage (extension – stretch-shortening cycle) of the whole body relative to snow and speed, especially higher speed.

Tynell

Sommerfeldt

Tynell

Sommerfeldt

Other reasons for bent arms have been given. Arnd Hemmersbach connects Kjolstads bent arms with his extremely high turn-over. This explanation follows the reasoning expressed above that sprinting acceleration speed requires a reduction in the moment of inertia in a higher frequency recovery phase, and that naturally requires a shorter lever. Marco Selle explains Bjorn Lind's arms bend sharply to absorb the shock of the very aggressive "stabbing" character of sprint double-poling. To my knowledge, the natural extension response to higher velocity in longer distances has not been described. What does appear in good skiers is that the bend remains relatively constant in the initial phase of the poling.

Whatever the case, I have not encountered any proof that poling is stronger because of a 90 degree angle. And even broad correlation is not proof of causality. Certainly poling will not be stronger if the arm exceeds 90 degrees by coming closer to the chest, with the core push being directed through the elbows, unless that is proved otherwise by actual measurements through a range of speeds and compared to other movement s solutions.

For the moment I conclude the way Arnd Hemmersbach began: “Foremost, it is interesting to see the variety in the double-pole technique of these athletes, all of whom are world-class.” And we have not begun to comprehensivey describe how poling variants effect the weighting and unweighting patterns of the gliding ski.

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Kjolstad

Piller-Cottrer

Piller-Cottrer