Biomechanische Analysen von Skatingtechniken im Skilanglauf
Biomechanical Analyses of Skating Techniques in Cross-Country Skiing
by Univ. Ass. Dr. Stefan Lindinger (Austria)
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[excerpts from the study which is both a comprehensive historical review of skating studies and a critical comparison of the most recent research]

p.12. [In previous research] Questions have not been discussed about the ideal push-off technique, the optimal poling action with various skating techniques, or even the meaning of the swing components of the body parts for leg and poling push in the sense of a qualitative consideration.

p.41. There are various movement solutions among the world class skiers.

p.43. [Following Schwirtz, 1994] These different patterns in maintaining velocity among the best skiers shows the breadth of variation in the possible solutions in V1.

p.44. Hoffman, Clifford and Bender (1995) emphasize in their conclusion that it is important to analyze the manner of velocity production also at the highest speeds because it is precisely there that significant changes occur. Misunderstandings can arise if we generalize the results of studies with limited velocity spectrums. [ex. problem with USST/CXC poling study]

p. 51. Bilodeau, Rundell, Roy and Boulay (1996) also attribute importance to the muscle contraction speed. The speed of muscle contraction is cross-country skiing is relatively high in some circumstances in classic technique and also at high speeds in skating, and a greater power impulse within short stretch-shortening cycles of both leg- and pole thrust brings greater acceleration of the system and with it greater stride length. [How do we focus on the SSC here? Do current explanations and learning models emphasize this at all?]

p. 52. [Among other aspects, the following are mentioned] Stronger effort of the torso in poling and more pronounced leg push-off on the weak side in V1 (Humphreys, Street, Smith, 1993). More pronounced pendulum action of the swing leg in diagonal and better use of gravity forces as an addition to muscle power (Norman, Caldwell and Komi). [The nature of swing leg motion seems little understood today, even though the Russians have emphasized it since the mid 70's.]

p.54. The large individual variations in the biomechanical parameters of V1, compared to the rather small and in part unsystematic changes during competition lead the author to the thought that explanation models in the future outght to analyze more on the basis of individual data than on groups of skiers. [It is clear he has read systems-dynamic research!]

p. 55. The velocity difference *within* the skating cycle is for the author the decisive criterion for a technique. [my italics.]

p. 58. A group of seven top athletes [biathlon skiers] who showed the best performances produced single curve velocities.

p. 59. A group of seven top athletes [biathlon skiers] with good performances with double curve

velocity patterns also show steep clim□□ in velocitiy at the beginning of the cycle (powerful push-off on the weak side.
p. 59. The upper body during the bending [forward during poling] was far enough turned to the ski of the strong side that the shoulder axis and the gliding ski stood at right angles, and thus the body weight can be totally shifted. *Immediately after the poling push on the strong side has ended* the leg begins it forwards-effective push. [Italics mine]

p. 60. It proved to be that the highest performing athletes exhibited the smallest [side-to-side] center of mass path, and the divergence from direction of travel also the smallest. [Does not mean that center of mass faces the direction of travel; does show that forward speed itself reduces side-to-side movement]

p. 68. [In analyzing skating] The disadvantages arise in the expensive installation of a system in a specially prepared track, the small number of connected strides in an analysis trial, and the missing possibility of measuring forces diagonal to the direction of glide, as is critical in skating. (Komi, 1987)

p.69. [To date] There have hardly measurements been taken of the dynamic distribution of pushing forces and friction forces under the edge of the ski.

p. 79. Schwirtz (1993) sees in the differing poling power pattern between right and left in V1 a deficit, that is, a performance potential and demands as simultaneous as possible a contact point and power release of the poles with equal force delivery.

p. 83. [Weak side] The force climbed more steeply at the beginning and higher (ski touch-down without being picked up by the poles) and it came to prominent unloading (at about 50% of the support phase) through an essentially even *more prominent glide leg extension (first knee angle extreme), during which the skier stood up as a whole and brought his arms forward and up*. The second acceleration up to the second peak force and the following force decrease was introduced with a short readying movement (fast, light knee bending) at the beginning of the weight shift and completed by the push-off extension (significantly smaller path of extension). [The extent of this glide leg extension, coupled with the swing forward and up of the arms/shoulder seems to me not totally appreciated. cf. p. 52]

p.85. [Similarly] The authors lay particular importance on the phase of glide-leg extension in V2 in its practical training consequences. It serves the momentary unloading (recovery) and is characterized by a clear knee- and hip extension. [In its latter part the unloading also unweights/frees the ski, which is at the point of increasing rate of friction, i.e. dying.]

p. 86. If one models this phase actively, this means to actively shift the lower leg forward during the glide, as one does in diagonal technique just before the kick. This lessens the loss of velocity by giving an additional impulse, before the leg then bends in pre-loading, the ski edges and the kick extension is complete. (Lindinger & Mueller, 1995)

However, primarily in the gentle climbs this glide leg extension in this emphatic form is today not considered as essential. Good technicians try to keep the glide phase more short relative to the total cycle and as quickly as possible initiate the next kick in order to maintain their cycle velocity. [I have seen this in some but not others, all top skiers. Hjelmeset and Svaertedal are examples of those who maintain it, Techmann less so, and I am not ready to call Smirnov, even Gunde Svan, old style. Also:

when the speed of movement reaches a certain point, we no longer can keep up with it perceptually. I would therefore have to see some high-speed cinematography to validate this point.]

p. 86f. The maximal amplitude of the lateral shiftig of the center of mass in V1 was about 20cm, in which case this shift was strongly dependent on terrain (climb). A sideways variance of 20cm was considered small and a positive element in technique. A comparison of the lateral movement of the center of mass and head provided interesting information. With both [only two?!] test skiers it was clear that the head reached the point of maximal shift sooner than the center of mass, and reached the middle sooner as well. This phenomenon was observed with V2 as well.

The authors interpret this as pointing out that the head plays an important steering role in weight shift to the side....The head determines the “direction of pull” of the total system and orients itself in the direction of the tip of the glide ski. The weight can thus be brought as a whole over the ski and be in a position for the pressure build-up on the edge when pushing off.

p. 87. It was interesting that in the flight phase [of V1] both skiers displayed an outward rotation (maximal 47 degrees) immediately after the end of the push-off. He authors view this as negative, since the total system experiences thereby an outward rotation, and core stabilization in the following glide phase would require too much energy. Besides that it delays the rapid weight shift to the other side (leg closing), since the segments (ski leg) for a moment drift away in the opposite direction and have to be brought back again.... This phenomenon was observable in V2 as well but less so. [Part of the drifting away problem can also be seen in the hip joint/swing point of the leg pendulum drifting backward, with a loss of forward touch down point on that side.]

p. 89. ….pull with the nose toward the ski tip and hold the shoulder axis at a right angle to the glide ski (Lindinger and Mueller, 1995).

p. 93. Interestingly the increasing velocity had a significant influence on the demands of the poling, that is, the defined variables relative to double-poling inccreased with V1. The authors explain this by concluding that the engaged forces in double-poling are directed more effectively in the direction of travel and thus for an acceleration of speed require less heightening of applied force than in V1 poling. [This would seem to validate the point, made by RT and Schwirtz that a hang pole and push pole in V1 is effective that making a poling side de facto one-legged double-pole. I see this priority, along with control of outward rotation, at work with Kuenzel and Angerer. The two elements seem to occur together. I counter the difference by practicing leading with the “weak” pole.]

p. 97. The maximal speeds between the skating techniques showed no significant differences. Double-poling was on avarage 9% slower than the skating techniques.

The largest maximal poling forces among the skating techniques were found in V2. Here values of 22.7 +/-2.3 % of body weight (BW) to 31.5 +/-5.6% BW were achieved across the entire velocity spectrum. The greater maximal poling forces can be explained by the fact that in this technique no unloading takes place from leg work. [More explanation needed]

The average poling power per cycle/stride showed higher values with increasing speed for all techniques besides V2. The authors conclude that in V2 additional impulse forces to raise the velocity are generated predominantly through leg work. The assumption that in V2 with increasing speed the poles work more and more effectively and that therefore the average force per cycle/stride no longer climbs is not shared by the authors. [This may support the explanation that more bent arms in V2 is not because that position generates more force but because with a smaller radius of motion reduce the moment of inertia and are thus able to keep up with the frequency of the legs.]

p. 98. At maximal speeds V2 alternate and V1 showed significantly lower values that double-poling for the parameters maximal poling force, average poling force per stroke and average poling force per cycle. These results point out that with these two techniques the torso/core is not fully loaded, i.e. engaged in order to reach highest velocity. It would be interesting to know whether these maximal forces in the two techniques arise at the initiation of the poling (impact of body mass) or during the push. No assertions are made in this regard, however. (Millet, Hoffmann & Candau, 1998) [This study was conducted on roller skis and thus requires that caveat. My own study leads me to the view that poling forces drop rapidly after the initial third of the arc. Research supports this, but does not suggest that the remainder of the arc should therefore not be completed. Doing so robs the stroke of both the secondary "push" part of the poling as well as inertial and stretch-shortening cycle forces.]

Leg work plays a decisive role above all at the highest speeds with all skating techniques. The cycle lengths and this glide path/distance of the skier and ground contact time (smaller ski angle to direction of travel [with increasing speed]) increase. Pole contact times, however, progressively decrease as the arm work can hardly keep up with the speed any more and become ineffective. The highest values for double-poling are reasonable because the forward impulse in this case can only be done through arm work.

p.103. Greater overlapping of the leg and poling impulses in the inefficient patterning of arms and legs correlates with lower leg push-off impulses. A synchronous push-off pattern of arms and legs in skating on a climb lessens the forces and moments of the forces engendered through the chain of leg segments. The criterion for the quality of skating technique should be the time of the force impulse overlapping, according to the authors. The optimal value for this criterion lies at zero...(Clauss& Hermann, 2000) [In other words, poling completes before push-off is accomplished, i.e. virtually separate movements...an example of "open" rather than "closed" cinematic chain.]

p. 105. [Looking at the curves of effective and less effective pressure in the foot, as the push-off begins].....the heel force began to fall off, the forces at the ball climb dramatically and reach their maximal value after the mid-foot force. The temporal sequence of the force maximums and the strong climb in force indicated a pronounced extension at the ankle [plantar flexion] towards the end of the push-off. [This interpretation of Clauss & Hermann fails to account for distinct gathering of critical forces through the ball of the foot during the eccentric loading/preflexing of that area right from the initiation of the push-off....Dillmann's mistake repeated]

p. 112. Schwirtz (1994) [Ansgar Schwirtz, biomechanist and co-author, with Georg Zipfel, of the German Ski Federation's official Cross-Country Skiing coaches' education curriculum] has concerns about Scherrrer's (1993) overemphasis on the aspect of the "lead hand" or "lead arm." He rejects this terminology in his technique description because it ought not to be a must to place the pole of the "leading arm" further forward. The danger exists that the work of the other pole becomes meaningless and that it functions even further to the rear and thus has little effective function. From the biomechanical point of view it would seem to make sense that both poles act as simultaneously as possible and at the same height, without a particular difference to a "leading arm." Slight variances occur in part due to the position of the skis, but that should not be required as a designated element of technique.

p. 116. In the described extreme terrain from which this [leading arm] technique derived it is a must for effective movement....[rationale here is not convincing, needs biomechanical basis. My take: it started early in skating, in imitation of Gunde Svan and promoted by the Norwegians, without analysis, as the "hang pole" and "push pole."]

p. 213 [In V2] The drop in velocity happens during the glide leg extension to the right and left, which also can be seen as preparation for the respective impulse phase, in which the skier brings himself into position for the following forward impulse.
p. 215. The more efficient the double-pole push can be formed, the more the speed which can be accepted from the leg push-off to accelerate the skater system.

p. 215. While the skater can prepare the leg push-off through the leg push-off flexion and increasing weight shift (build up of the edge grip [?]), the double-pole push accelerates the skater system to a certain speed through strong application of arms and upper body. As skiers 2 and 3 show, this speed can be picked up by the leg work and yet further raised in the overlapping phase between double-pole push and leg push-off extension and beyond that into the last third of the leg push-off.

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In V2 it is [also] a matter of the muscle action of a stretch-shortening cycle (SSC), and more precisely at the speeds run here (4.56m/s to 5.23m/s) of the type of slow SSC with the duration of the muscle action over 250 ms, that is around 600ms......During the leg push-off flexion the active leg musculature is stretched and operates eccentrically in this phase. Energy can be stored in the elastic structures of the muscle tendon complexes (pre-loading) and then let loose at the leg push-off extension in the conentric manner of the musculature, which elevates the performance potential of it. The leg push-off flexion can thus be seen as push-off preparation. The efficiency of the SSC (leg and arm work) will presumably be substantially higher in sprinting, where the velocities are much higher.

p. 230. The more efficiently the double-pole push can be formed with strong upper body engagement and maximal arm extension, the more speed can be taken up from the leg push-off and expanded (V2 and V2 alternate).

p.232. It is interesting that all three skiers reached the height of their arm swing [forward] velocity at approximately half of the static phase of the support leg. The arm and pole segments, moved by the shoulder musculature, are sharply accelerated forward here. (V2, V2 alternate)

p. 284. In the phase of the preparation for push-off with the leg flexion and beginning transfer of weight to the side the athlete exhibits and increasingly balanced force distribution, which indicates an even loading of the inner edge of the foot and thus the edge of the ski. The barely noticeable forward leanout the at the beginning with slightly higher forefoot forces is compensated during going lower [flexion], the point of gripping wanders exactly to the middle of the foot and the end of the push-off preparation reaches a perfect central position, as the leg push-off model requires. [Basis for this push-off model?
I wonder about the dynamics of the foot still. Do the forefoot forces just "wander" back to mid-foot, or does the flexion cause them to touch back ever so briefly from the spring point still anchored in the forefoot, in order to pre-load plantar flexion? I thin he has the sequence of weight distribution right but maybe not the mechanics which produce it, perhaps because there are no devices which measure that. The stiffness of the current skate boots determines this result as well, Flexible soles need to be tested, as the Swedes have done with a klap-skate imitation.]

p.287. Towards the end of ground contact the ski is slightly accelerated by the ankle(-spring) extension. [But this is the *result* of powerful and early plantar flexion. There can be substantial stretching/pre-loading without force against another surface being indicated. Is this true?]

p. 294. The normal push forces reached at the ski surface on the poling side [V2 alternate] are significantly greater. That is because on that side through the longer support/glide times (gliding and pushing off) the force can be applied longer. [Incorrect. It *appears* to be applied over a longer distance because the speed is higher. What we see is not greater time of application but rather greater distance covered in the same time. Also: extending the time of application of force results in greater *work* , shortening the time of application of force results in greater *power/speed*. In racing time is a divider, not a multiplier.]

p. 316. …..In V1 the torso is strongly involved in the poling and remains bent/flexed right into the final third of the pole push. The weight of the body is laid on the pole[s] and strengthens the eccentric work of the arms.

p. 323. The almost balanced distribution of the ground reaction forces between fore- and rear-foot in the eccentric and concentric phase up the the beginning of plantar flexion documents also in V2 simulation [on a slide board] the maintenance of an effective middle-position, even if in total a slight forward attitude is apparent, which results in a constant minimal relative dominance of fore-foot forces. [Confirms my reflections on p. 284-287. Also, on a slide board the forward movement of skiing is obviously missing, which fundamentally changes foot dynamics. For example, you don't “sit” in the middle of a forward moving wave. Nor can you push off at 90 degrees to the ski because you cannot keep up with your own speed that way..... unless plantar flexion in fact initiates the push-off and is thus early light and rapid enough to ride or slightly accelerate the movement.]