LONGITUDINAL KINEMATIC CHANGES WITH THE DIAGONAL STRIDE IN HIGH-SCHOOL GIRL CROSS-COUNTRY SKIERS

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The purpose of this study was to describe longitudinal kinematic changes associated with the diagonal stride in high-school girl skiers. An emphasis was placed on the poling phase of the movement and the stretch-shortening movements that can observed at the elite level. Four high-school athletes were videotaped once each year for 4 years. Angular relationships and kinematics variables were evaluated. Most athletes showed steadier trunk angles, and more consistent elbow extension in later years. Elbow angles decrease at the beginning of the poling phase, stretching the elbow extensors in the initial part of the propulsive phase. All athletes progressively increase knee angle during the glide phase but do not show a short but significant flexion just prior to pole plant and initiation of the "kick", which was exhibited by the model. Coaches can benefit from angular analyses as their emphasis in training is often related to body positions during various phases of the movement.

KEY WORDS: cross-country skiing, kinematics, performance, technique.

INTRODUCTION: Cross-country skiing has undergone a series of changes in the past thirty years, from the introduction of the skating technique to the new sprint competitions that have be seen since the 2002 Olympic games. However, the traditional diagonal stride (classical technique) is still very popular and usually taught first to the novice skier.
Biomechanical markers of performance (such as stride length, stride rate, center of mass displacement and velocity) in elite racers have been identified for all cross-country skiing techniques. Studies have shown stride length to be a better determinant of performance (average speed over a race) for any given technique in comparison to stride rate (Bilodeau et al., 1996; Smith et al., 1989; Smith & Heagy, 1994).
The diagonal stride can be described as the arms and legs moving in a diagonal fashion, with a push-off performed by the arm and leg of the contralateral side (Nilsson et al., 2004). The focus of diagonal stride investigations evaluated temporal characteristics (such as time of glide and recovery) compared to the propulsive phase at the elite level (Bilodeau et al., 1992; Dufek & Bates, 1987; Komi, Norman, & Caldwell, 1982; Lindinger et al., 2009). However, technical changes associated with the developing high-school athlete have yet to be addressed. The purpose of this study was to describe selected longitudinal kinematic changes associated with the diagonal stride in high-school girl skiers. An emphasis was placed on angular changes associated with the poling phase of the movement.
METHOD: Over a 4-year period, more than 30 female high-school skiers from the Duluth, MN area participated in this project, but only 4 skiers were involved in each of the data collecting sessions and are described here (age = 13.1 ± 1 years in Year 1). The participants were also compared to a "model" subject (age = 17), a high-school girl skier selected by various coaches to have an excellent technique. All subjects signed a consent and a parental permission was obtained in accordance with the University of Minnesota IRB procedures.
Participants proceeded through a self-guided warm-up and performed the diagonal stride along a straight and flat track (0% grade) of approximately 150 meters in length groomed specifically for this project. The subjects used their own equipment, which changed in size from Year 1 to Year 4, and the coaches waxed the participants' skis prior to data collection. Temperatures during data collection were remarkbly similar each year (-6 to -8 °C), but snow conditions in Year 4 were described as "icy", necessitating a Klister "kick" wax for the participants. The participants were asked to ski at race pace, trying to maintain a constant speed through a 20-meter marked zone of the track. Two GEN-LOCK synchronized 60-Hz cameras (JVC-TKC1380) were used to videotape the performances. These cameras were

placed on specialized tripod heads, allowed panning and tilting since movement occurred over a large calibration area (ViconPeak, Centennial, CO).
One cycle for each performance was randomly chosen for digitizing. The video images were manually digitized using a 23-point, 16-segment model (DeLeva, 1996), and the position-time data from each camera processed with Peak Motus 8 using the Linear Transformation Technique (DLT) to create the 3-D model (Abdel-Aziz, & Karara, 1971). Cycle length (CL), velocity (v), and percent poling phase time (%PP) were calculated. Angular relationships related to trunk, pole, elbow and knee were also calculated.

RESULTS: Unfortunately, no data were collected in Year 3 due to poor snow conditions. The Model skier (M) is described for Year 2 only (the last year she skied for this project). There is no particular order to the listing of each individual subject. Table 1 describes performance markers for each athlete. Most skiers had a poling phase (PP) relative time between 30 and 37%, with S1 and S2 showing the largest variation between years.

Table 1. Selected kinematic markers of performance

	Cycle Length (m)					Velocity ($m.s^{-1}$)					% Poling phase Time				
	M	S1	S2	S3	S4	M	S1	S2	S3	S4	M	S1	S2	S3	S4
Year 1		5.88	5.54	4.03	4.85		3.96	3.70	3.41	3.31		30.3	32.2	36.6	36.4
Year 2	6.01	6.31	5.93	5.09	5.57	4.74	4.12	4.68	4.02	3.88	31.6	28.3	31.6	35.5	32.6
Year 4		5.08	5.08	4.63	4.42		3.71	4.12	3.56	3.31		35.4	29.7	35.0	35.0

Trunk and elbow angles changes during the poling phase are important factors associated with the overall performance of the skiers. All skiers showed a steadier trunk angle in the later years (slope is more vertical), with less angle variation through the plant. However, all skiers (except M and S2 in Year4) seem to bring the trunk up before the end of PP as can be observed in Figure 1.

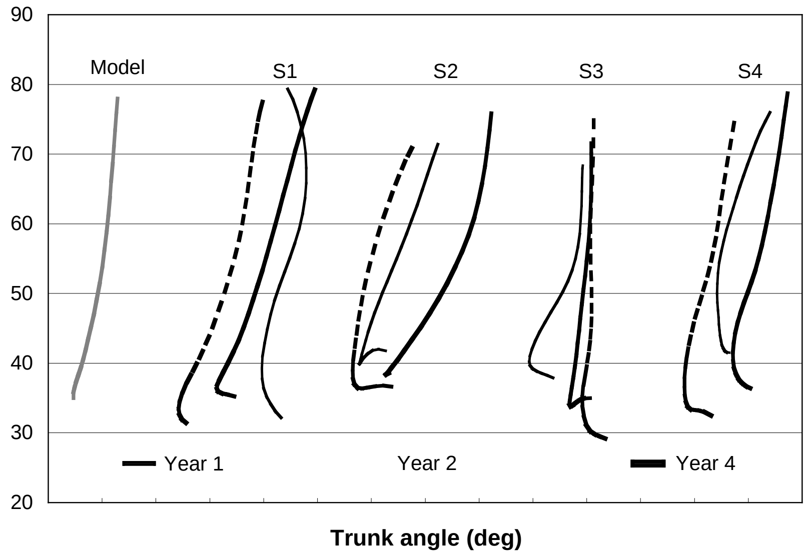

Figure 1. Individual trunk angle changes during the poling phase of the diagonal stride.

The elbow angular changes exhibit a "stretch-shortening" movement by which the athlete initially flexes the elbow, stretching the triceps, and subsequently extends through the poling phase. This can be observed in all skiers in one of the various years (Figure 2), but it is not consistent through the years. Only S1 and S2 showed a progression from Year 1 to Year 4.
In the glide prior to pole plant on the contra-lateral side, the knee angle is held at a relatively constant angle as can be observed in M between 25 and 50% CT in Figure 3. The poling

phase occur at approximately 50% of cycle time (CT). Only M truly exhibit a slight extension prior to pole plant, which also initiates the kicking action (pushing down on the ski).

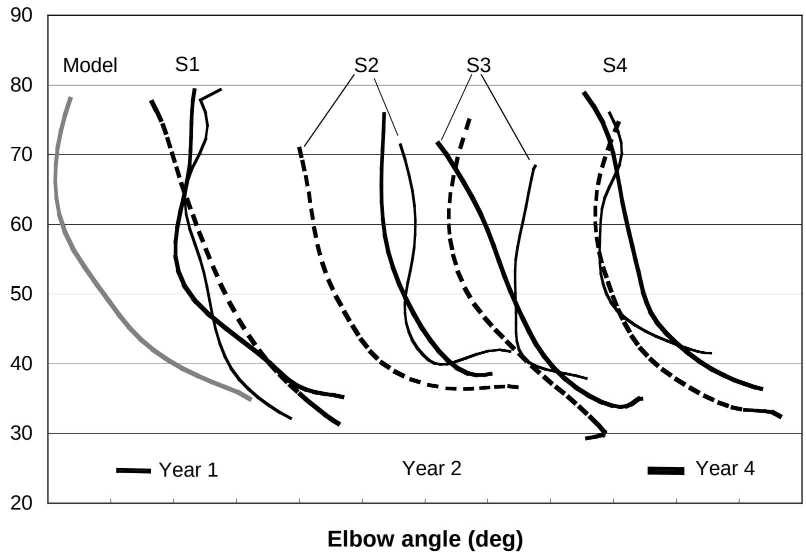

Figure 2. Individual angular changes during the poling phase of the diagonal stride.

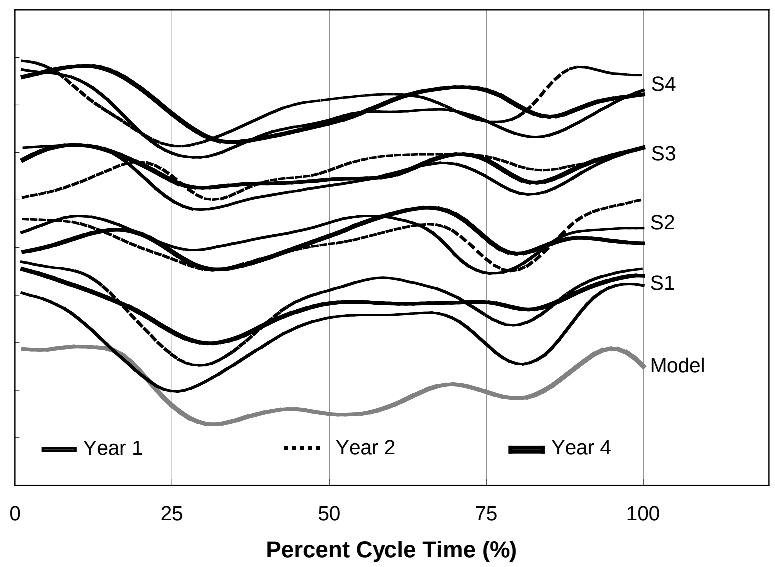

Figure 3. Knee angular changes for one cycle

DISCUSSION: The athletes showed progress from Year 1 to Year 2, but conditions in Year 4 may have contributed to the decline in performance-related markers. Observed PP relative time was similar to elite levels (Bilodeau et al., 1992; Dufek & Bates, 1987). However, angle relationships during the poling phase expressed marked changes. Athletes showed more consistent variations in their trunk angle, expressed by the the more vertical curves of Figure 1, with a trunk angle variation of approximately 10 degrees in Year 4 from 15 degrees in Year 1. All skiers (except M and S2 in Year 4) bring their trunk up before the end of the poling phase. While this action is very short in absolute time, it suggests that the athlete may attempt to use trunk extension to extend the poling phase. It is not certain whether this action can be beneficial to maintaining speed and whether it positively affects performance. Elbow angles variations suggest that the athletes initially flex the elbow at the beginning of the poling phase, stretching the extensor muscles before engaging into forceful elbow extension (Figure 2). This small flexion was reported by Lindinger et al. (2009) during uphill roller skiing with elite skiers, but this movement peculiarity is not commonly observed at the high-school level.

Knee angle should remain fairly constant through the glide phase (from about 25 to 50% of CT). Only M exhibits the slight knee extension followed by the small and quick knee flexion, which allows a vertical force to compress the ski against the snow, initiating the “kick” (Smith, 2000). This angular change was not observed in the other skiers. Instead, there is an extension of the knee throughout the glide phase, suggesting a constant movement toward the initiation of the “kick”. Only S3 in Year 4 keeps the knee angle constant through the glide phase. This constant increase in knee angle raises the center of mass, but the lack of a sudden knee flexion at the initiation of the kick suggests these athletes must find another strategy to accelerate the center of mass down to compress the ski against the snow.

CONCLUSION: This project described longitudinal changes associated with the diagonal stride in cross-country skiing. In particular, it focused on the non-elite athlete at the high-school level. Most athletes showed improvement from Year 1 to Year 2, but not necessarily from Year 2 to Year 4. Measurable changes can be observed in individual athletes, and technique deficiencies can be detected from year to year as evidenced by angular changes. Environmental differences will affect performance markers such as speed, stride length and rate, but body positioning measures such as angular relationships tend to be independent of these environmental changes and could be helpful to the development of the young skier.

REFERENCES:

Abdel-Aziz, Y.I., and Karara, H.M. (1971). Direct linear transformation from comparator coordinates into object space coordinates in close-range photogrammetry. *Proceedings of the ASP/UI Symposium on Close-Range Photogrammetry*, 1-18. Falls Church, VA: American Society of Photogrammetry.

Bilodeau B., Boulay M.R., & Roy B. (1992). Propulsive and gliding phases in four cross-country skiing techniques. *Medicine & Science in Sports & Exercise, 24*, 917-925.

Bilodeau B., Rundell, K.W., Roy B., &. Boulay, M.R. (1996). Kinematics of cross-country racing. *Medicine & Science in Sports & Exercise, 28*, 128-138.

Dufek, J. & Bates, B. (1987). Temporal gait characteristics of cross-country skiers. In B. Jonsson (Ed.), *Biomechanics X-B*. Champaign, IL: Human Kinetics.

Komi, P.V., Norman, R.W., & Caldwell, G. (1982). Horizontal velocity changes in of world class skiers using the diagonal technique. *Exercise and Sport Biology* (pp. 166-175). Champaign, IL: Human Kinetics.

Lindinger, S.J., Göpfert, C., Stöggl, T., Müller, E., & Holmberg, H.C. (2009). Biomechanical pole and leg characteristics during uphill diagonal roller skiing. Sports Biomechanics, 8, 318-333.

Smith, G.A., Nelson, R.C., Feldman, A., & Rankinen, J.L. (1989). Analysis of V1 skating technique of Olympic cross-country skiers. *International Journal of Sport Biomechanics, 5,* 185-207.

Smith, G.A., & Heagy, B.S. (1994). Kinematic analysis of skating technique of Olympic skiers in the men's 50 km race. *Journal of Applied Biomechanics, 10*, 79-88.

Smith, G. A. (2000). Cross-country skiing: Technique, equipment and environmental factors affecting performance. In V. Zatsiorsky (Ed.), *Biomechanics in Sport. IOC Encyclopedia of Sports Medicine Series* (pp. 247-270). Oxford, UK: Blackwell Science.

Viitasalo, J.T., Norvapalo, K., Laakso, J., Leppavuori, A.P., & Salo, A. (1997). The effects of 50 km racing on ski kinematics in the Falun world championships in 1993. In E. Mueller, H. Schwameder, E. Kornexl, & C. Raschner (Eds.), *Science and Skiing* (pp. 88-96). London, UK.: E & FN Spon.

Acknowledgement

Thank you to the students in the exercise science program who have helped with data collection, setting up equipment in fairly “cool” temperatures. Special thanks to Corey Speaker for his help in digitizing, processing data and his attention to detail.