KNEE AND BOOT 3D KINEMATICS DURING FORWARD ACCELERATION IN ICE HOCKEY SKATING MEASURED WITH A MOBILE CAMERA ARRAY

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The purposes of this study were three-fold, the first purpose was to determine the spatial kinematics at both the knee and ankle joint, the second objective aimed at identifying differences in the kinematics of the joints over consecutive push-offs (PO) and the third objective was to verify the adequacy of using a novel method for video-data acquisition for the analysis of ice hockey skating. Statistically significant (ANOVA, =0.05 & Scheffé post-hoc) differences between knee joint Range of motion, angle of maximum and initial knee flexion were found between the first and subsequent PO. Ankle joint data were more similar than knee joint values. This uniformity at the ankle joint could result from hockey skate boots being very stiff. Future research using this approach is warranted and should focus on the effects of skate design on the skating motion as well as include the hip joint into the analysis.

KEY WORD: kinematics, method, hockey.

INTRODUCTION: There is a lot of literature on the mechanics of speed skating, one group even identifying an evolution in the skating stride over distance and time during acceleration, from a motion similar to running towards a gliding motion (DeKoning, et al., 1995). Of great interest for the biomechanics community, the same group has led the sport of speed skating into a revolution through an improvement to the skates based on a biomechanical analysis (De Koning, et al., 2000). Previous research into ice hockey skating is somewhat antiquated and limited in scope. More recent research (e.g. Turcotte, Pearsall,Montgomery, 2001; Wu et al. 2003) has tended to focus on the effects of various equipment improvements on performance than on skating biomechanics per se. The joint kinematics of this skill have not been the subject of many publications, at least to our knowledge. One of the main limitations in the study of skating kinematics is the distance covered by skaters from stride to stride. As indicated in Lafontaine & Lamontagne (2003), alternative approaches to conventional biomechanical data collection methods have been developed but seemed inappropriate for the study of skating kinematics. Therefore another approach was deemed necessary to study skating kinematics, and this need spawned the moving camera cart method. The focus of the current paper is on the experimental data obtained during on-ice testing of hockey players performing starts from a stationary position using the moving cart approach. The objectives of the on-ice testing were two-fold: the main objective was to describe and compare the spatial kinematics of the right knee joint and ankle joint from the initial push-off (PO1) to the third right foot push off (PO3). The secondary objective of the study was to refine and demonstrate the usefulness of the data acquisition method. The third objective of this study was to determine if a kinematic evolution similar to the one found for speed skating existed for ice hockey skating.

METHODS: Seven adult male hockey players consented to take part in the current study. All subjects wore similar skates (Graf model Supra 703, size 9 US) for data collection to control this variables' effect on joint motion. Subjects also wore a form fitting black garment to enhance marker contrast. All testing was conducted at the University of Ottawa arena within a 6-week period and was approved by the Research Ethics Committee. External markers were applied to the garment over palpable anatomical landmarks to favour similar placement of markers between subjects. To limit inter-tester variability, the same person applied the markers on the subjects for all testing sessions. A total of nine (9) markers remained on the subjects during actual data collection (three per segment) with eight (8) additional markers (Figure 1) installed on the subjects prior to data collection to allow for the Joint Coordinate Systems (JCS) to be established (Grood & Suntay, 1983). A JCS was used in order to allow for measurements to be expressed relative to relevant anatomical axes. According to the knee axes defined with the JCS, the motions are expressed as follows: motion of the tibial reference system about the femoral fixed axis represents flexion (+)[FLEX] and extension (-)[EXT]. Motion of the tibial reference frame about the floating axis: tibial abduction (+)[ABD] and adduction (-)[ADD] and motion of the tibial reference frame about its longitudinal axis is expressed as internal (-)[I ROT] and external (+)[E ROT] rotation. The ankle motions under investigation are defined as follows: foot reference frame motion relative to tibial medio-lateral axis is defined as dorsi (-)[DFLEX] and plantar flexion (+)[PFLEX]. Motion of the foot reference frame about the tibial longitudinal axis is defined as foot abduction (-)[ABD] and adduction (+)[ABD] while motion about the ankle reference frames' floating axis constitutes inversion (-)[INV] and eversion (+)[EVER].

The equipment used in this study was identical to that used during the validation of the method (Lafontaine & Lamontagne, 2003). A slight modification was made however to the guide rails after preliminary tests showed that the railings used in the laboratory were not fully adequate for on-ice testing. For on-ice testing, a single guide rail made of a half PVC pipe was screwed into the ice with both of the carts' left wheels tracking in it, while a research assistant skated to push the cart along the ice.

During data collection each subject performed 10-15 full-out starts (forward accelerations). Subjects were instructed to initiate motion by pushing off with their right skate. From the recordings, trials comprised of three consecutive strides (two push-offs [PO] compose a stride) were selected. The entire blade-ice contact period for the right foot was analysed for each right-foot push-off. The time base was normalised to 100% of contact time for all trials. The joint motions were calculated and filtered (Butterworth low-pass digital filter, 10 Hz cut-off), from digitised data obtained with the APAS system, using in-house analysis software (JointKinematics2).

Each subject was treated independently with his own trials pooled together to establish his average skating kinematics for each push-off. The data consist of three angles at the knee and ankle for each push-off. A three-way ANOVA (PO1 X PO2 X PO3) was run to identify statistically significant differences (a =0.05) between push-offs for each studied angle for each subject. More specifically, the ROM, initial and final angles as well as the maximal and minimal angles obtained for each motion will be compared using the ANOVA. A Scheffé post-hoc will reveal where the statistically significant differences were found. An important limitation of the current study is that ankle motions are believed to be equivalent to skate boot motions, although using boot mounted markers has been shown to introduce an underestimation of ankle bone movement (Al Hadi, 2002).

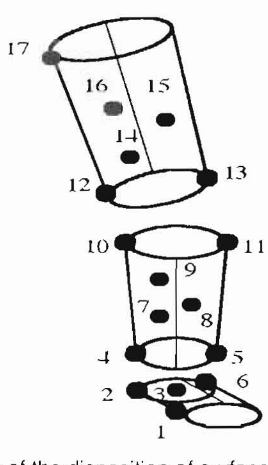

Figure 1: Schematic representation of the disposition of surface markers; note that markers 4, 5, 6, 10, 11, 12, 13 and 17 are only used during anatomical calibration trials.

RESULTS: As stated earlier, the results presented herein represent the mean values obtained for each subject during PO1, PO2 and PO3. Figure 2a-b illustrates two different knee flexion strategies used by subjects to initiate motion during PO1. Subjects 1, 3, 5 and 7 use a similar strategy of gradually increasing knee flexion during the first 70% of the push-off followed by an extension during the last 30% of the task. Of note, all these subjects keep their knees in flexion (~20-30 degrees) when their skates lose ice contact. The strategy used by subjects 2 and 6 consists of keeping their knees flexed at a relatively constant angle during the entire task. All subjects initiated ice contact for PO2 and PO3 on a flexed knee and gradually extended it over the duration of ice contact. Although the strategies used during the second and third push offs were similar for all available subjects (S1, S2, S6 & S7), the ranges of motion were consistently higher during the second push off versus the third one except for subject 2. During PO1 the maximum knee flexion angle ranged from 13 degrees (S2) to 57 degrees (S5), with most falling in the 30-40 degrees range. For PO2 the maxima ranged from 40 degrees (S2) to 83 (S6) while during PO3 the range was a bit narrower, with values falling between 51 (S2) and 84 (S7) degrees. The minima during PO1 were between 10 (S1) and 32 degrees (S7), during PO2 between 3 (S2) and 45 degrees (S6) and for the third push-off minimal values ranged from 48 degrees of flexion (S6) to 18 degrees of extension (S2). Initial and final values for knee flexion varied between tasks, falling anywhere between 9 degrees (S1PO1) and 84 degrees (S7PO3) for initial values and 18 degrees of extension (S2PO3) to 45 degrees of flexion (S6 PO2). Tibial abduction versus time curves illustrate that the skaters increased tibial abduction from ice-contact towards the midpoint of the push-off and gradually decreased the tibial abduction angle as they progressed towards toe-off.

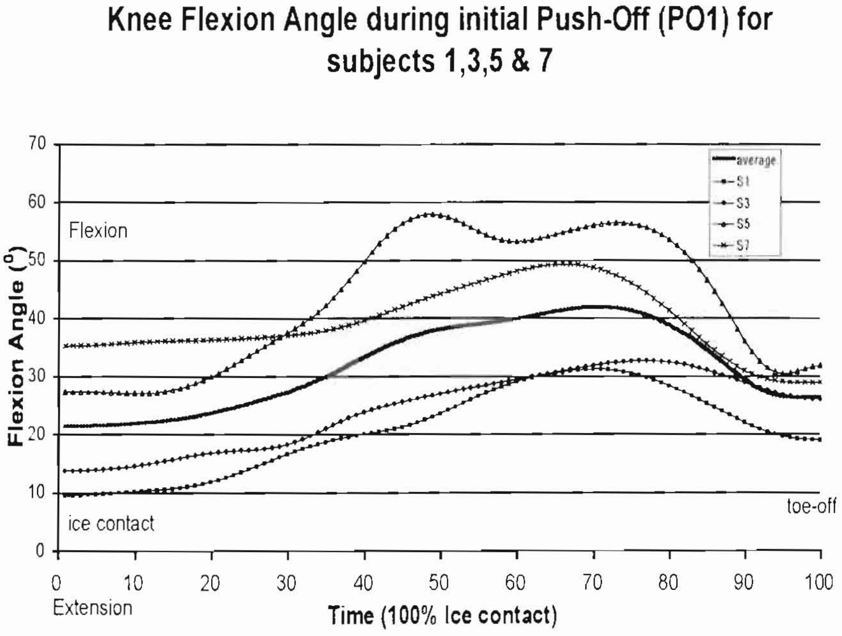

Figure 2a: Knee flexion angle during initial push-off of a forward skating acceleration task (PO1) for subjects 1, 3, 5 & 7.

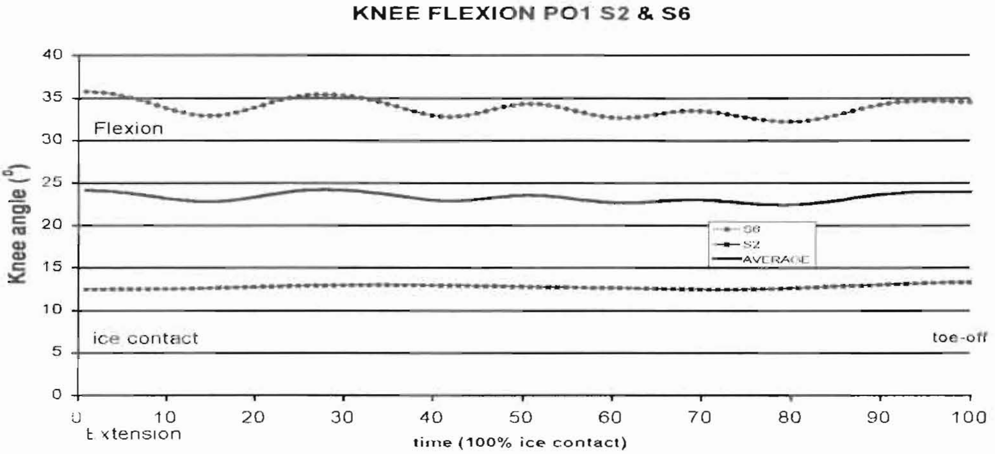

Figure 2b: Knee flexion angle during initial push-off of a forward skating acceleration task (PO1) subjects 2 & 6.

No plantar flexion was measured for any of the subjects. What was observed however is a gradual increase in dorsiflexion as load is applied to the foot. This increase in dorsiflexion was more clearly observed during the initial push-offs. During the later push-offs (PO2-3), this angle remained mostly constant during the contact phase and decreased near the end demonstrating a return towards the neutral position. Ranges of motion for ankle dorsiflexion demonstrated similar tendencies to those measured for knee flexion, with the ROMs for PO2 tasks being slightly larger than those obtained for PO3, and both of these measures being larger than the ROM for PO1.

DISCUSSION AND CONCLUSIONS: The main purpose of this study was to discriminate between joint angles while subjects performed forward skating acceleration tasks. As was expected the ROM obtained at both joints increased with the number of strides. The kinematic differences that were obtained support that as skaters gain speed, the skating motion changes. This change in skating motion concurs with what De Koning et al. (1995) identified for speed skating.

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