EFFECTS OF FATIGUE ON FORWARD, MAXIMUM VELOCITY IN ICE HOCKEY SKATING

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The purpose of the study was to compare the skating mechanics of skilled and less skilled hockey skaters under fatigued and non-fatigued conditions. 14 subjects participated in the skating task. Each was video taped from two views on three occasions during a 380 m task. The first occasion was considered non-fatigued and the latter two fatigued conditions. The video was analysed via a three dimensional APAS. The independent variables were skill level and fatigue level. Several dependent variables reflecting skating mechanics were also measured. Statistical analysis indicated several changes accompanying fatigue. The variables affected included stride length, skating velocity, and range of motion and angular velocities in the lower limbs. It was concluded that fatigue does have significant detrimental affects on skaters at both skill levels prompting rapid redeployment during game situations.

KEY WORDS: ice skating, kinematics, fatigue, skill level

INTRODUCTION: It has been suggested (Green, 1987) that fatigue results in an inability to maintain a desired physical capability and that it is a persistent threat in ice hockey. As such, it has the potential to disrupt all aspects of performance. In addition, since hockey involves alternating periods of high energy expenditure and rest, brief periods of fatigue can exist throughout the duration of a game and become even more prevalent during the later stages. Previous research has attempted to outline the basic mechanical aspects of maximum speed skating (Marino, 1977; Marino and Weese, 1978; Marino, 1984; McCaw and Hoshizaki, 1987; Kirchner and Hoshizaki, 1989). In addition, Marino and Potvin (1989) and Marino and Goegan (1990) reported on several changes that take place in segmental kinetics of skating under fatigued conditions. These studies, however, did not deal extensively with kinematic descriptors of the movement pattern. To date, there is no evidence of research dealing with the effects of fatigue on skaters of different ability levels or on kinematic and postural aspects of the skating motion. In light of gaps in the literature, the purpose of the present study was two fold: first, to examine the differences in skating kinematics between skilled and less skilled performers; and, second to identify changes that occur in skating kinematics when an individual becomes fatigues during a maximum effort, anaerobic work bout.

METHODS: Fourteen subjects were selected for participation in the study. Eight were considered highly skilled and had experienced ice hockey play at either university or junior levels. Six were regarded as less skilled and, although all were proficient skaters, none of these had experiences similar to the skilled group. Each subject wore his own skates and was allowed sufficient time on the ice to warm up prior to the task performance. Subjects skated a predetermined route, including stops and starts, in a task that was designed to last for approximately one minute. The total distance covered during the task was 380 m. Based on previous research (Marino and Potvin, 1989) this time was believed to be sufficient to promote anaerobic fatigue. Each subject was videotaped three times during the skating task. The first taping occurred early in the task in a non-fatigued condition and the second and third taping occurred late in the task when the subjects were fatigued. All video taped trials were recorded at the same location on the ice to eliminate the effects of prior stops, starts and turns. Also, an adequate distance to reach maximum speed was ensured. The subjects were fitted with reflective markers at appropriate joint centres and each trial was taped from two views using standard video cameras set at 45 degree angles from the path of motion. The video was subsequently subjected to three dimensional analysis using the Ariel Performance Analysis System (APAS). Direct Linear Transformation (DLT) processing was used for data transformation and the cubic spline curve fitting technique for data smoothing.

Calibration was performed using a 12 control point cube which was video taped on the ice then removed prior to testing.
There were two independent variables in the study: subject performance level and state of fatigue. Skilled and less skilled subjects were subjected to repeated measures under a non-fatigued condition and two fatigued conditions. Both fatigued conditions were measured late in the skating task on consecutive passes through the video taping area. Thus, the two fatigued trials were meant to reflect two different levels of fatigue. Twenty-three postural and kinematic variables were chosen as dependent variables in an attempt to differentiate between skilled and less skilled skaters and between the fatigue conditions. Two way Analysis of Variance with repeated measures on fatigue was used to identify statistically significant differences at less than the .05 level of significance. Orthogonal means comparisons were used as a post-hoc multiple comparisons technique where warranted. Test, re-test confirmation and comparison with previous research was used to ensure the reliability and validity of the data.

RESULTS AND DISCUSSION: The total skating task times, recorded in seconds, were 57.1 (SD = 1.59) and 63.1 (SD = 2.34) for the skilled and less skilled groups respectively. The difference is statistically significant at $P < .05$. This confirms the validity of the assignment of subjects to the two groups. Although the non-fatigued skating velocities of the skilled group were somewhat higher than the less skilled group the differences were not statistically significant. This probably reflects the fact that the forward skating section of the course was the easiest section. The significant differences in total time to complete the course probably indicates the skilled subjects higher ability to handle stops and starts and cornering. Like velocity, stride lengths and rates were somewhat different between skilled and less skilled groups but the differences were not statistically significant. Other postural variables did reveal statistically significant differences between skilled and less skilled groups. The skilled group was able to achieve better touchdown position of the foot relative to the centre of mass at the end of the recovery phase. In addition, the skilled group exhibited significantly more knee flexion at touchdown. This variable has been hypothesized by several researchers including Page (1979), Holt (1978) and McCaw and Hoshizaki (1987) to be important in preparing the skater for a forceful thrust during the subsequent propulsive phase of the stride. Overall, it appears that with only a couple of significant exceptions, skilled and less skilled maximum speed mechanics are approximately the same. For the most part, the skating techniques of the two groups did not vary significantly. In only a very few instances were significant differences found. This would corroborate the findings of McCaw and Hoshizaki (1989) who reported few differences in technique between intermediate and elite skaters. They did report several differences between novice skaters and these two groups but the current study did not employ novice subjects so that comparison was not possible.
The effects of fatigue were also monitored. The results of comparison of non-fatigued trials with the two fatigued trials are shown in Table 1.

Table 1 Mean Values for Selected Kinematic and Postural Variables Pooled for Skilled and Less Skilled Skaters Under Non-Fatigued and Fatigued Conditions

Variable	Non Fatigued	Fatigued 1	Fatigued 2
Horizontal Velocity (m/s)*	9.27	7.71	6.97
Stride Length (m)	3.61	3.79	3.63
Stride Rate (st/s)*	2.57	2.03	1.92
Single Support Time (%)*	83.5	78.5	78.6
Double Support Time (%)*	16.5	21.5	21.4
T. D. Position (cm)*	11.3	7.1	4.5
T. D. Knee Angle (deg)*	102.3	110.9	16.4
Total Knee Ang. Disp. (deg)*	60.6	51.0	45.1
Thigh Ang. Vel. (deg/s)*	169.0	112.5	101.3
Shank Ang. Vel. (deg/s)*	51.5	34.3	32.9

* Statistically significant differences at $P < .05$

Since only minor between group differences were found, the data for the two groups were pooled in order to consider the effects of fatigue. Several important differences were found to occur for the whole group as a result of fatigue. The pooled velocity values reflected the effect of fatigue. In the non-fatigued condition, the mean velocity value was 9.2 m/s. Velocity decreased to 7.71 m/s and 6.97 m/s respectively for the two subsequent fatigue trials ($p< .01$). It is interesting to note that the decreases in velocity were accompanied by decreases in the rate of striding. Stride rate declined from 2.57 st/s in the non-fatigues trial to 2.03 st/s and 1.92 st/s in the fatigued trials ($p < .05$).

Under conditions of fatigue, the muscular effort required to produce a high rate of striding is apparently difficult to achieve. These results tend to confirm the findings of Marino and Goegan (1990) that the primary changes in segment kinetics resulting from fatigue were in the work rates and energy transfer rates. Like stride rate, these variables are also time dependent. It is interesting to note that while the overall time of stride increased with fatigue, the two components of the stride time showed different trends. The single support time comprised 83.5 % of the stride time in non-fatigued skating and this decreased to 78 % in the fatigued trials. In contrast, double support increased from 16.5 % of stride time to 21 % as the skater became fatigued. In both instances, the differences in % times between non-fatigued and fatigued conditions were statistically significant. The second main component of velocity, stride length, showed no significant affects of fatigue. The values for this variable were 3.61 m, 3.79 m, and 3.63 m respectively for the three fatigue conditions. As suggested in previous studies (Marino, 1977; McCaw and Hoshizaki, 1987; Marino and Potvin, 1989) the glide component of the stride ensures a fairly consistent stride length across a wide range of skating velocities. The longer stride times associated with fatigue would allow a longer period of time for the skater to glide, thus ensuring a normal stride length.

In addition to the basic stride characteristic changes discussed above, several postural changes also accompanied the onset of fatigue. The touchdown position of the recovery skate, the knee angle at touchdown, the total range of motion of the knee, and the angular velocities of both the thigh and shank all changed significantly between the non-fatigued and fatigued conditions. Taken as a whole, these changes reflect the fact that when fatigued, the skater is not able to put the support leg in a favourable position to begin the subsequent support and thrust phase. Also, it appears that the skater is unable to generate the levels of angular velocity, in the leg segments, during a fatigue state that would produce velocities and stride rates similar to the non-fatigued state.

PRACTICAL APPLICATIONS: The results of this study indicate the importance of the time components in the ice skating stride. Players should be encouraged to emphasize a high stride rate without compromising the other thrust and glide aspects of the skating pattern.

Sufficient knee bend at contact should be taught to ensure a full range of motion of the knee during the thrust phase of the support period. Conditioning exercises, both on and off ice, should emphasize increases in strength and power of the musculature responsible for both knee and hip extension. Such exercises should be performed at high velocity to mimic the action of the leg in skating. Finally, the observation of the onset of fatigue and its effects on basic skating mechanics in a relatively short period of time has several implications for the sport of hockey. Not only does the maximum velocity of skating decrease with fatigue, but other skills such as starting, stopping, accelerating and turning would also be expected to deteriorate under conditions of fatigue. The first fatigue trial in this study was recorded no longer than 42 seconds after the start of the task for any subject. This further supports the notion proposed by other researchers and by coaching practitioners that shift (on-ice) time should be kept below 45 seconds, especially if play is continuous and at high intensity.

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