CHAPTER 4

RESULTS & DISCUSSION

In line with the aims of this study, first descriptive data of the subjects sampled for this study, and their representativeness as ice-hockey players is presented and discussed. This is followed by ANOVA comparisons of maximal physiological responses in each of the tests, and the development of a regression for the Modified Skating 20 MST (MS20MST). Thereafter, correlations and regressions between treadmill $\dot{V}O_2$ max as the criterion and performance achieved (maximal speed) in each field test to identify the best test for ice-hockey players. Finally, subjective rating of the tests by the subjects is presented.

4.1. Subject Characteristics and Experimental Conditions

From the original pool of twenty-six subjects (Table 4.1) who participated in the study, only sixteen (Table 4.2) performed all the tests and were used in most calculations (paired comparisons) unless otherwise specified (e.g. for the development of the MS20MST regression equation, n=21). We point out immediately that a repeated ANOVA with missing data procedure was also run including all the subjects yielding the same results but a fully paired sample was used to report descriptive statistics and ANOVA results. The mean age of subjects in this study was 32.2±12.2 years, older than those reported in other studies of ice-hockey players, which range from 10.8 to 27.3 years (refer to Appendix B). The mean height and weight of subjects in this study was 177.2±6.8 cm and 80.1±12.8 kg. This is at the lower range of the physical characteristics of adult male ice-hockey players reported in other studies where height ranges from 176.2 to 187.7 cm, and weight ranges from 77.9 to 93.9 kg (Appendix B). Subjects in this study had a wide variety of fitness levels, some having trained relatively regularly during the summer and some had just returned to Montreal after their summer holiday, having done no training. This was an important aspect of the study, as $\dot{V}O_2$ max is a good predictor of endurance potential when a group of athletes with vastly different performance capabilities are studied, but is relatively poor predictor when athletes of similar ability are evaluated.

Table 4.1: Subject Characteristics of the Original Sample (n=26)

	Age (yrs)	Years of hockey (yrs)	Height (cm)	Weight in lab (kg)*	Weight with full kit (kg)**
Mean	32.2	22.2	177.2	80.1	91.8
SD	12.2	11.4	6.8	12.8	14.5

* measured in the laboratory on a calibrated balance scale on the day of treadmill testing
** measured in the ice-arena on a bathroom scale with subjects wearing full kit and holding hockey stick, on the day of MS20MST or SMAT

Table 4.2: Subject Characteristics of the Sample Used (n=16)

	Age (yrs)	Years of hockey (yrs)	Height (cm)	Weight in lab (kg)*	Weight with full kit (kg)**
Mean	32.1	22.0	176.7	78.7	88.6
SD	12.7	12.3	7.4	15.0	15.1

* measured in the laboratory on a calibrated balance scale on the day of treadmill testing
** measured in the ice-arena on a bathroom scale with subjects wearing full kit and holding hockey stick, on the day of MS20MST or SMAT

The mean number of years of ice-hockey experience that subjects in this study possessed was 22.0±11.4 years, was higher than any of the literature reviewed in this study, that ranges between 3.8 to 10 or more years (refer to Appendix B) indicating that the subjects were experienced, proficient skaters. In a study by (Houston & Green, 1976) players had at least eight years intensive hockey training before reaching university levels.

The importance of applying on-ice skating fitness tests only to subjects who are proficient skaters was demonstrated by Léger (1981) who showed large interindividual variations in the energy cost of skating, and a large standard error of estimate of the regression line (6.3 ml kg^{-1} min^{-1} or 22 % on average) that were systematic and associated with the technical skills of the skaters. When a battery of ice-hockey tests is administered to young hockey players, the more complex the skill aspect, the greater the difference between competitive and recreational players (Montgomery, 1988). Forward skating speed is a less discriminative test in comparison with puck control or agility tests for overall hockey performance but is more discriminative to specifically assess aerobic fitness while skating, assuming that skating skill is sufficiently mastered. Experience in skating and technical skating skill is an important factor in obtaining accurate results. Compared to professional players, Leone, Léger, & Comtois (2002, unpublished) showed a higher energy cost of skating in younger elite age-group hockey players, which was explained by the age-group players having a lower mechanical efficiency. Leone *et al.* (2007) suggest that the greater the skill and experience in skating that the skater possesses, the greater the importance for on-ice assessment.

The ability to rapidly accelerate, maintain skating speed, rapidly decelerate, proficiency in cornering, and agility (ability to change direction quickly and accurately) were all important requirements in the tests performed in this study, in order to obtain accurate results. Young, James & Montgomery (2002) state that reactive strength of the leg extensor muscles has some importance in change-of-direction performance, but that other technical and perceptual factors that influence agility performance should also be considered.

Full hockey equipment (kit) includes shoulder, elbow, and shin pads, hockey jersey, gloves, socks, pants, helmet, and stick. Subjects in this study were weighed in the laboratory wearing only running shorts, and then again in the ice arena wearing full kit, with skates and hockey stick, before the SMAT or MS20MST. A small sub sample of four subjects were also weighed wearing a tracksuit, helmet, stick, and gloves, as required for the FAST. The mean added mass when dressed in full kit was 9.9±2.2 kg, and the added mass for the FAST ranged between 3.2 and 7.3 kg (measured in the ice-arena on a bathroom scale with subjects wearing a tracksuit, helmet, gloves and holding hockey stick). Although Léger, Seliger & Bassard (1979) state that equipment weight and design increases the cost of skating by 4.8 % and reduces the endurance time by 20.3 %, Leone *et al.* (2007) are of the opinion that hockey equipment has changed dramatically since then and that the effect of equipment, if any, today, is probably marginal, although tightness of some cloths may still impede the motion of skating. From the previously mentioned added mass in this study, one would surmise that $\dot{V}O_2$ (if directly measured) was higher in the tests where subjects were dressed in full kit and that maximal speed would be lower with equipment, thus yielding lower predicted $\dot{V}O_2$ max values. Therefore it is important to do the test in the same conditions used to develop normative data or regression to predict $\dot{V}O_2$ max (e.g. full kit for the MS20MST and SMAT, and partial kit for the FAST).

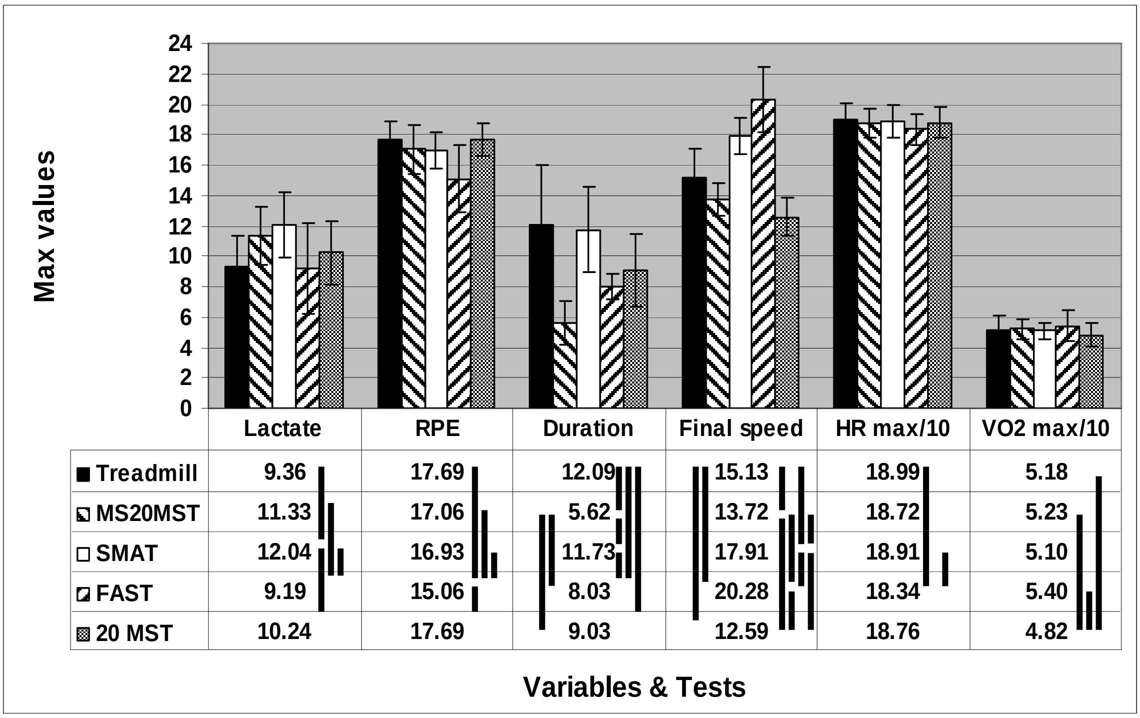
In this study, there were however, significant differences among the five tests with regard to test duration. Equipment weight may cause subjects to reach $\dot{V}O_2$ max at an earlier stage, thus reduce the duration of the test (and predicted $\dot{V}O_2$ max), but other factors (such as muscular fatigue due to stop-and-go, or inability to maintain a very high skating speed, and of course the duration of the stages, speed increase per stage and inclusion of a rest or not between stages) can also contribute to overall test duration.

Compared to a multistage oval ice skating protocol, Léger *et al.* (1979) state that the skated 20 MST with equipment more closely approximates the nature of skating seen in a game. Thus, an added advantage of both the MS20MST and the SMAT can both be performed on a regular arena ice surface with players wearing full hockey equipment, as in a game situation, thus proving to be very specific.

4.2. Comparison of Different Variables in All Five Tests

In accordance with the first aim of the study, to compare the MS20MST, SMAT, and FAST ice-skating tests to determine their common variance, repeated ANOVA (n=16) results are reported below according to each variable, namely maximal speed, test duration, maximal heart rate (final stage of the test), maximal Borg Rating of Perceived Exertion (RPE, using the 6-20 scale), maximal lactate, and maximal oxygen consumption ($\dot{V}O_2$ max). A posteriori test (Tukey-Kramer) was used to determine exactly where the differences are between each pair of tests since the ANOVA only determines whether or not differences exists among the five tests. The level of significance was set to $p<0.05$. Pearson correlation coefficients were also estimated for each variable obtained from the five tests. Figure 4.1 gives an overall view except for the Likert scales assessments (presented later). The significance of the differences is shown in Figure 4.1 by vertical bars joining pairs of values that differ significantly, and are discussed in more detail when reporting each variable. A detailed analysis is presented separately for each variable thereafter.

Figure 4.1: Comparison of Variables Between Various Tests (n=16)



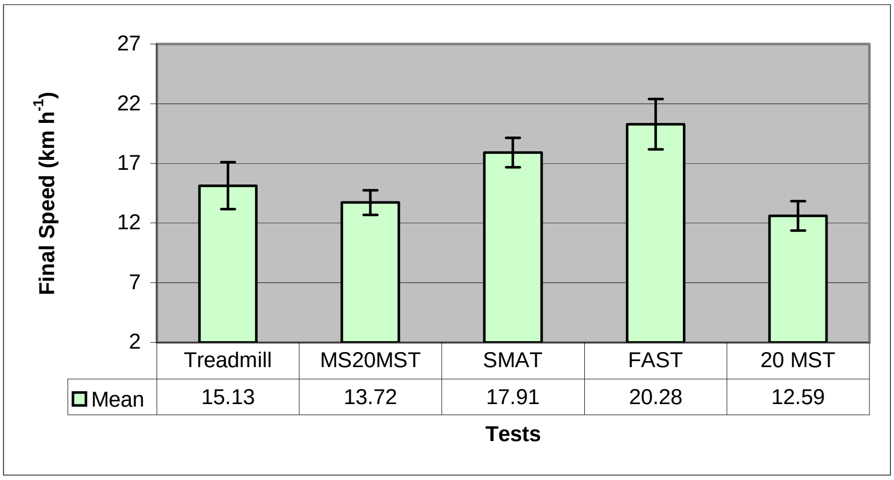
NOTE 1: Lactate is in mmol L^{-1}, RPE is on a scale of 6-20, duration is in min, and final speed is in km h^{-1}.
NOTE 2: HR and VO_2 max are divided by 10 so they could be plotted on the same graph. HR is in beats min^{-1}, VO_2 max is in ml kg^{-1} min^{-1}
NOTE 3: Pairs of values joined by a vertical bar are significantly different ($p \leq 0.05$)

There appears to be very little difference among tests with regard to HR and $\dot{V}O_2$ max, but some of these differences are in fact significant, and are indicated by the bars in Figure 4.1. The FAST clearly has a higher mean maximal speed, but a lower mean maximal lactate (than all the other tests, except the treadmill test), as well as a lower RPE than the other tests. The MS20MST has lower test duration than any of the other tests.

4.2.1. Final Speed

Mean maximal speed was determined in all tests and is shown in Figure 4.2. Mean maximal skating speed was progressively higher from MS20MST, SMAT, and FAST (13.72, 17.91, 20.28 km h^{-1}, $p \leq 0.01$).

Figure 4.2: Mean Maximal Speed (km h^{-1}) Comparison Between Tests (n=16)

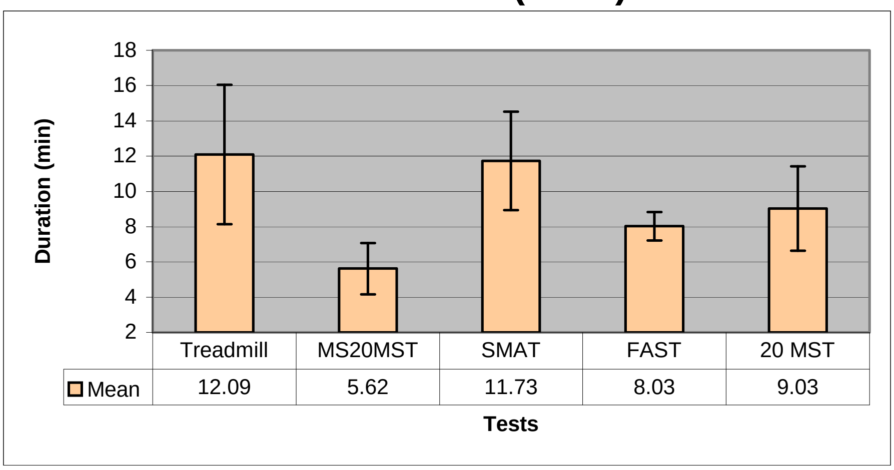


The fact that running and skating speed differ is not that important (because we know that the surface is different); however, it is interesting to compare maximal speed achieved for the three skating tests. Furthermore when comparing the skating field tests to each other, significant differences were observed between each of them ($p \leq 0.01$), which was expected. When comparing the MS20MST to the SMAT, they have a similar speed increment per minute, but the SMAT a 30 s rest period after each one minute stage, and has a longer course (45 m as apposed to 20 m in the MS20MST), requiring a lower frequency in direction changes and acceleration phases. Thus to reach the same speed in the SMAT is easier and for the same $\dot{V}O_2$ max as in the MS20MST, subjects reach higher speed in the SMAT. On the other hand, the FAST has no rest between stages, and has no stop-and-go pattern (the FAST is continuous and curvilinear), and the stages of the FAST become shorter and shorter meaning that the speed is increasing faster and faster (after every third length of the ice, exponential increase in speed). In the FAST, subjects obtained much higher final skating speeds, as the course is continuous and curvilinear (without stop-and-go) and allows subjects to build up and maintain high skating speeds. In other words, as the test progresses the subjects have to maintain new speed for less time which enables them to reach higher speeds. So even if that was expected, it needed to be statistically confirmed which it has been. This indicates that maximal speeds achieved in each of these three skating tests are different and each test applies different stimuli and demands different skills from the subjects.

4.2.2. Duration

Mean test duration values are shown in Figure 4.3. The highest mean test duration was obtained in the treadmill test (12.09 minutes, possibly due to the fact that it was the only test with stages that were two minutes long), followed by the SMAT (11.73 minutes, probably due to the 30 second rest periods after each one minute stage), 20 MST (9.03 minutes), and FAST (8.03 minutes). The MS20MST had the lowest mean test duration at only 5.62 min.

Figure 4.3: Mean Test Duration (Min) Comparison Between Tests (n=16)



When each field test was compared to the treadmill "gold standard", there were significant differences. The MS20MST duration was significantly less ($p \leq 0.0001$) than that of the treadmill test; in fact it was less than half of the treadmill duration. The FAST duration was also significantly lower than that of the treadmill ($p \leq 0.0001$). Furthermore, the 20 MST duration was also significantly lower than that of the treadmill test ($p \leq 0.0001$), which can probably be explained by the fact that the treadmill protocol had stages that were two minutes long, whereas those of the 20 MST were only one minute long.

When comparing the field tests to each other, they were all different ($p < 0.001$) from each other, except the FAST and the 20 MST. It seems that stages and acceleration in some protocols do not permit subjects to reach steady state at end of each stage making it difficult to eventually establish individual and valid % HR_{max}-% $\dot{V}O_2$ max calibration curve for training purposes or to estimate the average energy cost as a function of speed using end of stage $\dot{V}O_2$ values. Nevertheless as long as treadmill $\dot{V}O_2$ max and maximal speed are well correlated, maximal speed can be used to predict $\dot{V}O_2$ max which is the case for MS20MST and SMAT as is reported later.

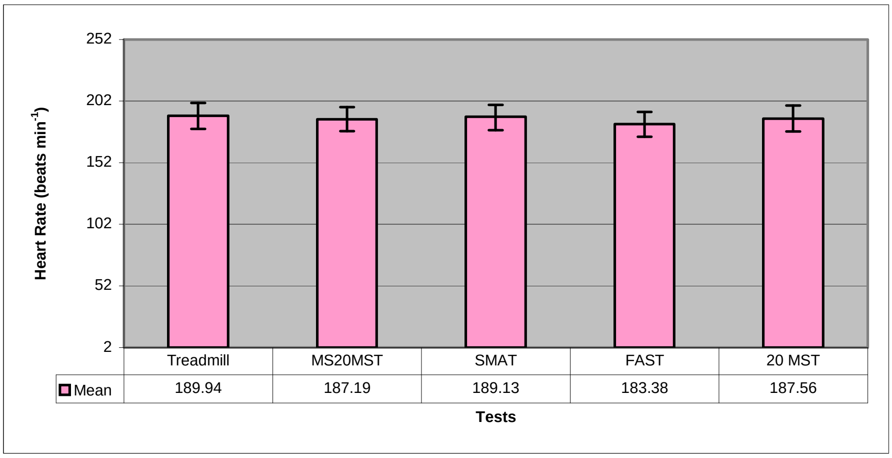
From another point of view, it is clear that MS20MST is the test with the shortest duration, making it the most time efficient. Thus, when ice-time is limited and expensive, it is still possible to administer an on-ice test, if it is time efficient, and for this purpose, the MS20MST would be the best.

4.2.3. Heart Rate

The maximal HR obtained in each test is an important factor in determining whether each test is as physiologically stressful as the others. The mean maximal HR for each test is shown in Figure 4.4. The FAST maximal HR was significantly lower than that obtained during the treadmill test (183.4 and

189.9 beats min^{-1} respectively, $p \leq 0.01$) while the other two skating tests also show a similar trend. Furthermore the FAST maximal HR was also significantly lower than that obtained in the SMAT (183.4 and 189.1 beats min^{-1} respectively, $p \leq 0.05$). No other maximal HR differences were observed.

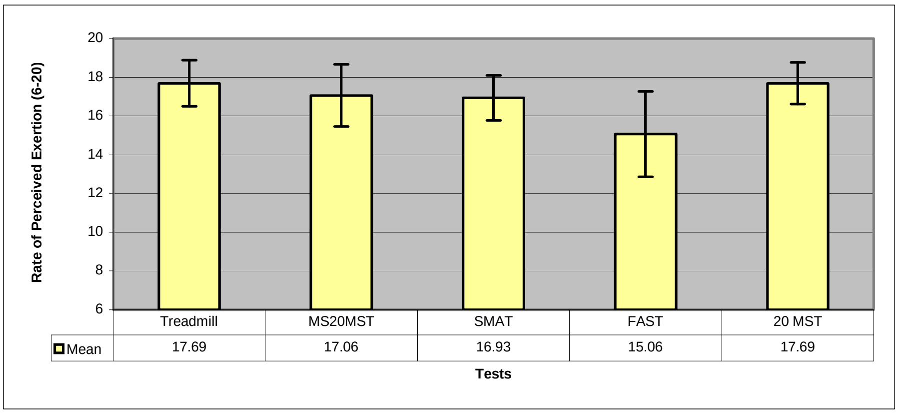
Figure 4.4: Mean Maximal Heart Rate (beats min^{-1}) Comparison Between Tests (n=16)



4.2.4. Rating of Perceived Exertion

The mean maximal Rating of Perceived Exertion (RPE) score on the 6-20 Borg scale (Appendix J) for each test is shown in Figure 4.5.

Figure 4.5: Mean Maximal Borg Rating of Perceived Exertion (RPE) Comparison Between Tests (n=16)



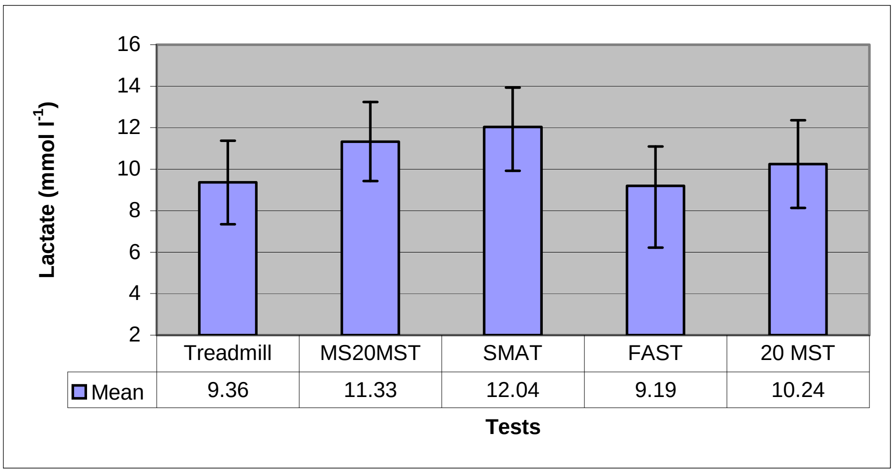
The FAST was subjectively perceived to be less difficult than any of the other four tests (15.06 vs. 16.93 and above; $p \leq 0.05$). No other differences were observed among the other tests. This perception is supported by the lower maximal lactate obtained in the FAST (see next sections). Furthermore, the perception of less physiological strain may be due to the fact that the FAST is curvilinear in nature (less muscular fatigue as it is continuous with no stop-and-go), and allows subjects to build up speed gradually, and maintain that speed, before the skating speed becomes very fast. Subjects were more often withdrawn from the test (whereas subjects in the other skating tests stopped voluntarily) because in the FAST subjects could not maintain the required speed of skating. Many of the subjects stated that they felt that the physiological strain was not as high as during the other skating tests, but that the skating speed required was too high to maintain, that being the reason for stopping in few cases or being with drawn from the test, thus, explaining the lower RPE ratings of the FAST. The lower lactate values in the FAST indicate that subjects could possibly continue physical exertion, but were unable to due to the high speed of skating and the difficulty and dangerous cornering at those high speeds. It seems that the MS20MST and SMAT have similar perceived intensity despite longer test duration in SMAT.

In summary, from the above it is clear that the skating tests are perceived to be easier, but physiologically, they are as taxing as the running tests. This perception may be due to the fact that ice-hockey players are more comfortable in and familiar with their training environment that with running, demonstrating the need for on-ice aerobic tests. Among the skating tests, the MS20MST has the shortest distance, and has the lowest test duration, but it is perceived to be the most difficult of the skating tests (probably due to the high frequency of stop-and-go, which causes muscular fatigue) although it is physiologically not dissimilar to the other tests.

4.2.5. Lactate

Mean maximal lactate scores (mmol L^{-1}) for each test is shown in Figure 4.6. The MS20MST and the SMAT yielded the highest lactate values, and the FAST the lowest, indicating a higher anaerobic contribution in both the MS20MST and the SMAT, as compared to the FAST and the running tests. This may indicate that the MS20MST and the SMAT are more hockey-specific than the other tests. The SMAT was significantly higher than the treadmill, FAST and 20 MST lactate (12.04, 9.36, 10.24 mmol L^{-1} respectively; $p \leq 0.001$) and the MS20MST lactate was significantly higher than the FAST lactate (11.33 and 9.19 mmol L^{-1} respectively, $p \leq 0.05$). The lowest maximal lactate value was obtained in the FAST. This is almost certainly due to the fact that the FAST is continuous without stop-and-go. The speed in the FAST becomes very fast as the test progresses, but the dominance of the aerobic energy system is still maintained. Unlike in the other tests where subjects voluntarily stopped the tests, subjects in the FAST were withdrawn from the test most often because the skating speed became too fast (and subjects could not keep up with the set pace), not because subjects perceived it to be too physiologically taxing (see RPE in 4.24 above) or because of excessive muscular fatigue (shown here by the fact that the FAST has the lowest lactate score among the five tests). Additionally, the high speed of skating cornering becomes very difficult and dangerous at very high speeds.

Figure 4.6: Mean Maximal Lactate (mmol L^{-1}) Comparison Between Tests (n=16)

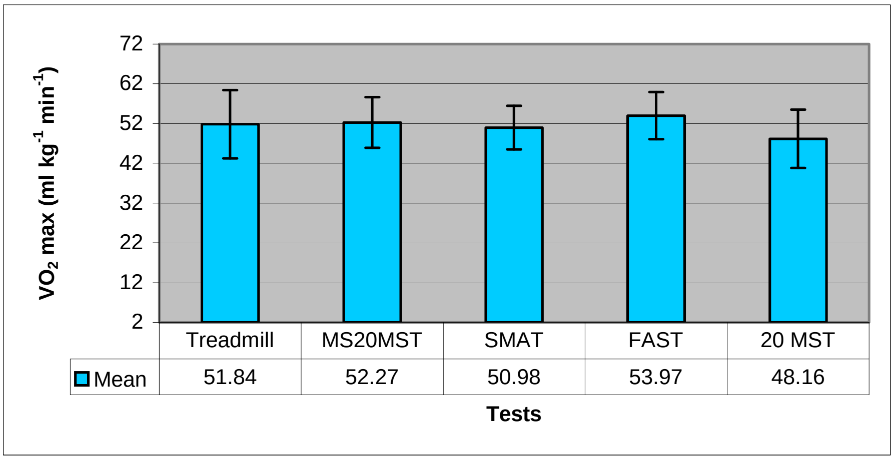


4.2.6. $\dot{V}O_2$ max

Predicted $\dot{V}O_2$ max values (ml kg^{-1} min^{-1}) for field tests were obtained using the original equation of each test and were compared to $\dot{V}O_2$ max directly measured on the treadmill and to each other. The mean maximal $\dot{V}O_2$ max for each test is shown in Figure 4.7. The highest mean $\dot{V}O_2$ max score was obtained in the FAST (53.97 ml kg^{-1} min^{-1}), followed by the MS20MST, treadmill, SMAT, and 20 MST (52.27, 51.84, 50.98 and 48.16 ml kg^{-1} min^{-1} respectively). The predicted 20 MST $\dot{V}O_2$ max (48.16 ml kg^{-1} min^{-1}) was significantly lower than the other tests except SMAT (48.16 vs. 51.84 to 53.97 ml kg^{-1} min^{-1}, $p \leq 0.05$). As found in this study where $\dot{V}O_2$ max did not differ significantly among skating tests (or among skating tests and the treadmill test), Léger, Seliger & Bassard (1979) found no difference between the $\dot{V}O_2$ max of ice-hockey players in three ice tests (20 m on-ice course with and without equipment, and 140 m oval on-ice course) and an incremental treadmill test.

The $\dot{V}O_2$ max obtained from the MS20MST was not significantly different from treadmill, which is expected since the regression was developed from treadmill. The mean of the 16 subjects used for the ANOVA is lower than the mean of 21 subjects used for the development of the equation (which was developed from all possible pairs of X and Y). If the equation was developed with the same 16 subjects, both means would be identical. The direct $\dot{V}O_2$ max measure obtained from laboratory treadmill running can be systematically high or low (Babineau *et al.,* 1999.), thus, it cannot be said for sure that the 20MST prediction underestimates $\dot{V}O_2$ max. Studies evaluating the accuracy of the 20 MST in predicting laboratory $\dot{V}O_2$ max and maximal velocity have reported contradictory results. Ahmaidi *et al.* (1992) showed that the maximal velocity determined during the 20 MST revealed a lower values than treadmill testing (16.3 %), but no difference between $\dot{V}O_2$ max values were found. Mc Naughton *et al.* (1996) state that the 20 MST overestimates the $\dot{V}O_2$ max, while St Clair Gibson *et al.* (1998) state that the 20 MST underestimates the $\dot{V}O_2$ max.

Figure 4.7: Mean maximal $\dot{V}O_2$ max (ml kg^{-1} min^{-1}) comparison between tests (n=16)



Development of the MS20MST Equation

In accordance with the second aim of the study, a regression to predict $\dot{V}O_2$ max for the MS20MST was developed, based on the final speed obtained in the MS20MST. $\dot{V}O_2$ max obtained by direct gas analysis whilst running on the treadmill is considered the "golden standard" by which the validity of MS20MST was established. Based on the analysis of 21 measurements of oxygen consumption ($\dot{V}O_2$ max), a multiple regression model analysis was run with laboratory $\dot{V}O_2$ max as the dependent variable and maximal speed (km h^{-1}), height (cm) and weight (kg) as the independent variables to determine the predictability and effectiveness of the $\dot{V}O_2$ max from selected variables, ultimately to assess the validity of the MS20MST as a significant predictor of aerobic capacity in ice-hockey players. The variables were selected by means of stepwise regression but only maximal speed was a significant predictor:

$\dot{V}O_2$ max =-33.337 + 6.24(speed); [r=0.74, SEE=11.2 %, n=21)

Where:

a) $\dot{V}O_2$ max is expressed in ml kg^{-1} min^{-1},

b) Speed is expressed in km h^{-1}.

The parameter estimates are shown in Table 4.3. With an r value of 0.74 and R^2 value of 0.523, we can see that 52.3 % of the variance in $\dot{V}O_2$ max is explained by the regression model. With a corresponding random error of 5.93 ml kg^{-1} min^{-1} (SEE) or 11.2%, the equation indicates good accuracy and the test is a good indicator of $\dot{V}O_2$ max but a large margin of error remains unexplained. A biomechanical efficiency index could possibly improve the equation, and should be tested in a future study.

Table 4.3: Regression Summary for Dependent Variable: $\dot{V}O_2$ max (n=21)

Variable	Beta	Standard Error of Beta	B	Standard Error of B	t(19)	p-level
Intercept			-33.3372	18.08071	-1.84380	0.080866
Final Speed	0.739828	0.154350	6.2402	1.30190	4.79318	0.000126

Fit statistics	
R	0.74
R-squared	0.547
Adjusted R-squared	0.523
Standard Error of Estimate (SEE)	5.93
F-Value	22.975
P value for F	0.00013

4.3. Assessing and Comparing the Validity of Each Test

In accordance with the second aim of the study, the external and relative validity of the three new practical ice-skating tests to predict maximal aerobic power ($\dot{V}O_2$ max) in adult male hockey players that have mastered their skating skills was assessed. First the correlations among the different variables in the different tests were established, and then the direct treadmill $\dot{V}O_2$ max ("gold standard") was used as the criterion variable (by comparing observed $\dot{V}O_2$ max to $\dot{V}O_2$ max predicted from original equations) to determine which test is better suited for the evaluation of the maximal aerobic power of ice-hockey players.

4.3.1 Correlations

Final Speed

There were a number of similarities between the final speed of the five tests (Table 4.4). MS20MST and SMAT correlate quite well with treadmill (r=0.74 and r=0.78, respectively) and very well with 20MST (r=0.83 and r=0.87, respectively) but much lower with FAST (r=0.58 and r=0.61, respectively). The 20 MST obtained the highest correlation with mean maximal treadmill running speed (r=0.94), and can be partly explained by the fact that the exercise modality is the same (running), as apposed to skating. This also demonstrates the validity of final speed of the 20 MST.

Table 4.4: Correlations of Maximum (Final) Speed Values

	Treadmill	MS20MST	SMAT	FAST	20MST
Treadmill	1	0.74*	0.78*	0.53*	0.94*
MS20MST		1	0.84*	0.58*	0.83*
SMAT			1	0.61*	0.87*
FAST				1	0.67*
20MST					1

* Correlation is significant at the 0.05 level

Duration

There were also a number of similarities between the tests (Table 4.5). The highest significant correlation with regard to test duration was between the treadmill and the 20 MST (r=0.93), even though the treadmill stage duration was two minutes as apposed to one minute in the 20 MST. Among the skating tests the MS20MST and the SMAT demonstrated the same correlation with treadmill test duration (r=0.68). Among the skating tests, the SMAT had the highest correlation with the 20 MST (r=0.84), followed by the MS20MST (r=0.82), and the FAST demonstrated the lowest but still significant correlation with 20 MST test duration (r=0.59). Furthermore, there was a good correlation between the MS20MST and SMAT (r=0.89).

Table 4.5: Correlations of Test Duration

	Treadmill	**MS20MST**	**SMAT**	**FAST**	**20MST**
Treadmill	1	0.68*	0.68*	0.50	0.93*
MS20MST		1	0.89*	0.55*	0.82*
SMAT			1	0.51*	0.84*
FAST				1	0.59*
20MST					1

* Correlation is significant at the 0.05 level

From the preceding results it is clear that the MS20MST has the shortest duration of all five tests, making it the most time efficient. Thus, when ice-time is limited and expensive, it is still possible to administer an on-ice test, if it is time efficient, and for this purpose, the MS20MST would be the best.

Rating of Perceived Exertion

Correlation coefficients are shown in Table 4.6. The only significant correlation between maximal RPE values obtained in the treadmill was with that obtained in the 20 MST (r=0.59).

Table 4.6: Correlations of RPE Values

	Treadmill	MS20MST	SMAT	FAST	20MST
Treadmill	1	0.25	0.43	0.28	0.59*
MS20MST		1	0.23	0.51	0.31
SMAT			1	-0.18	0.37
Fast				1	0.43
20MST					1

* Correlation is significant at the 0.05 level

The FAST seems to be perceived as being easier due to less muscular fatigue (continuous with no stop-and-go). This is supported by the lower maximal lactate obtained in the FAST. The physiological stress between tests is similar, as the mean $\dot{V}O_2$ max and the mean maximal HR, obtained during the FAST, are well correlated with the other tests, although FAST lactate was significantly correlated only with the MS20MST, treadmill and 20 MST. This perception of less physiological strain may be due to the fact that the FAST is curvilinear in nature, and allows subjects to build up speed gradually, and maintain that speed, before the skating speed becomes very fast. Subjects were more often withdrawn from the test (whereas subjects in the other skating tests stopped voluntarily) because they could not maintain the required speed of skating. Many of the subjects stated that they felt that the physiological strain was not as high as during the other skating tests, but that the skating speed required was too high to maintain, that being the reason for stopping or being with drawn from the test, thus, explaining the lower RPE ratings of the FAST. The lower lactate values in the FAST indicate that subjects could possibly continue physical exertion, but were unable to due to the high speed of skating and the difficulty and dangerous cornering at those high speeds.

In summary, from the above it is clear that the skating tests are perceived to be easier, but physiologically, they are as taxing as the running test. This perception may be due to the fact that ice-hockey players are more comfortable in and familiar with their training environment than with running, demonstrating the need for on-ice aerobic tests. Although the MS20MST has the shortest distance, and has the lowest test duration, it is physiologically not dissimilar to the other tests. The MS20MST may thus be the preferable test because it is economic with regards to time and because of its sport-specific nature.

Lactate

Correlation coefficients are presented in Table 4.7. When each test was compared to the treadmill "gold standard", there were correlations between the maximal lactate values for the treadmill and 20MST (r=0.58) and between treadmill and the FAST (r=0.60). Surprisingly, the MS20MST correlated with the FAST (r=0.53).

Table 4.7: Correlations of Lactate Values

	Treadmill	MS20MST	SMAT	FAST	20MST
Treadmill	1	0.28	-0.00	0.60*	0.58*
MS20MST		1	0.29	0.53*	0.28
SMAT			1	0.34	0.27
FAST				1	0.61*
20MST					1

*Correlation is significant at the 0.05 level

VO_2 max

Correlation coefficients are presented in Table 4.8. All the skating tests were significantly correlated with the treadmill and 20 MST, although the FAST correlations were much lower (0.41 and 0.69 respectively). The skating tests also significantly correlated with each other (the FAST again lower than the other tests).

Table 4.8: Correlations of VO_2 max Values

	Treadmill	MS20MST	SMAT	FAST	20MST
Treadmill	1	0.74*	0.73*	0.41*	0.84*
MS20MST		1	0.86*	0.69*	0.83*
SMAT			1	0.66*	0.87*
FAST				1	0.69*
20MST					1

*Correlation is significant at the 0.05 level

4.3.2 Predictive Validity of Field Tests

$\dot{V}O_2$ max obtained by direct gas analysis whilst running on the treadmill is considered the "golden standard" by which validity of other tests measuring the same variable ($\dot{V}O_2$ max) can be established, because of its universal use and because similar $\dot{V}O_2$ are obtained on the treadmill and on the ice (Léger, Seliger & Bassard, 1980). Results of criterion treadmill test could be expressed in $\dot{V}O_2$ max (ml kg^{-1} min^{-1}) or in maximal speed units (km h^{-1}). In general, correlations between maximal speed attained in field tests with criterion treadmill tests are slightly better when the results of the treadmill tests are in speed units. For example, for the 20MST, correlation was 0.84 with $\dot{V}O_2$ max units and 0.94 with speed units. That being said, the extent to which each field test correlates with the criterion test is not the same but the same trend is observed whether $\dot{V}O_2$ max or maximal speed units are used. Thus using $\dot{V}O_2$ max units, the FAST test is much less correlated with the treadmill test (r=0.41 with a SEE or 7.53 ml O_2 kg^{-1} min^{-1} or 14.7% of treadmill $\dot{V}O_2$ max mean) than the two other skating tests, MS20MST and SMAT, which have similar accuracy (r=0.74 and 0.73 with SEE=5.93 and 5.65 ml kg^{-1} min^{-1} or 11.2 and 11.0 %, respectively). With an r value of 0.84 and SEE of 4.69 ml kg^{-1} min^{-1} or 9.02%, the 20MST, is the best field test, assuming treadmill $\dot{V}O_2$ max is a proper criterion. Finally, the maximal speed attained on the treadmill compared to $\dot{V}O_2$ max obtained during the same test yielded a correlation of 0.84 with a SEE of 4.72 ml kg^{-1} min $^{-1}$ or 8.95%. These r and SEE values were obtained using the maximum number of subjects for each comparison (n=17 to 23) but almost the same r and SEE values were obtained using only data from the same 16 subjects that did all the tests. Refer to Table 4.9.

Table 4.9: Correlations and Standard Errors of Estimate Predicting Treadmill $\dot{V}O_2$ max and Maximal Speed from Field Test Maximal Speed

Treadmill (Y)	N	Predicted variable	r	SEE ml kg^{-1} min^{-1} or km h^{-1}	SEE %
MS20MST (X)	**21**	$\dot{V}O_2$ max	0.74	5.93	11.2
		Max speed	0.75	1.23	8.07
SMAT (X)	**20**	$\dot{V}O_2$ max	0.73	5.65	11.0
		Max speed	0.79	1.16	7.73
FAST (X)	**20**	$\dot{V}O_2$ max	0.41	7.53	14.7
		Max speed	0.53	1.59	10.6
20MST (X)	**17**	$\dot{V}O_2$ max	0.84	4.69	9.02
		Max speed	0.94	0.70	4.59

Regression analyses (scatter plot, correlation and SEE; n=16-23) between direct $\dot{V}O_2$ max (treadmill) and the maximal speed in each test to establish predictive models was done to check external validity and to compare the validity of each test in a pair design. Exponential regressions were run, but the relationship between each test and the criterion $\dot{V}O_2$ max was no better than with simple (linear) regression. Generally, the exponential regression produced a better fit than the linear regressions. Linear regressions between treadmill $\dot{V}O_2$ max and final speed in each test are shown in Figure 4.8-4.12. These figures illustrate the random variation on each side of the regression for each test. These results demonstrate that to achieve the same aerobic fitness level on the treadmill, one has to skate at high speed in the FAST, medium speed in the SMAT, and low speed in the MS20MST. It is true to say that some tests are not only not equivalent in terms of positioning or discriminating between subjects, but it can also be said that some (MS20MST and SMAT) are better than others (FAST) because the treadmill $\dot{V}O_2$ max is a valid criterion.

Figure 4.8: Treadmill VO_2 max as a Function of Speed in the Treadmill Test

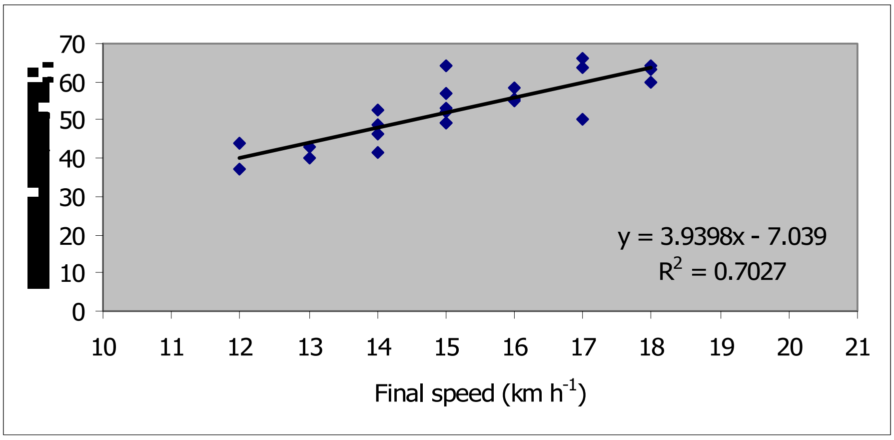


Figure 4.9: Treadmill VO_2 max as a Function of Speed in the MS20MST

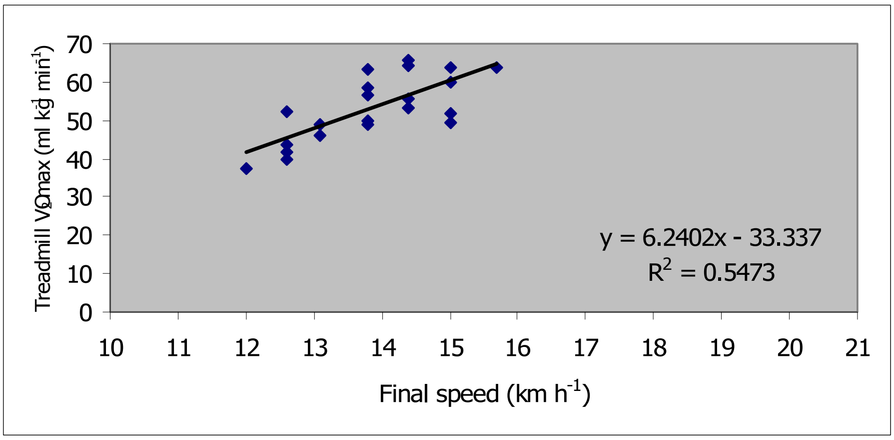


Figure 4.10: Treadmill VO_2 max as a Function of Speed in the SMAT

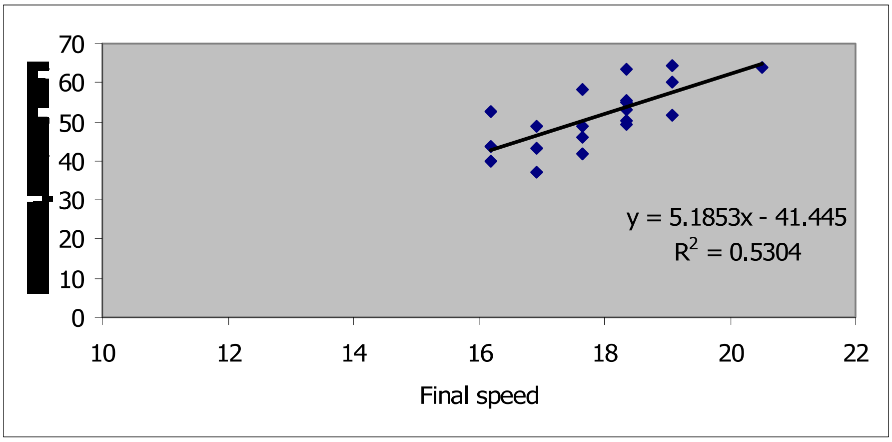


Figure 4.11 Treadmill VO_2 max as a Function of Speed in the FAST

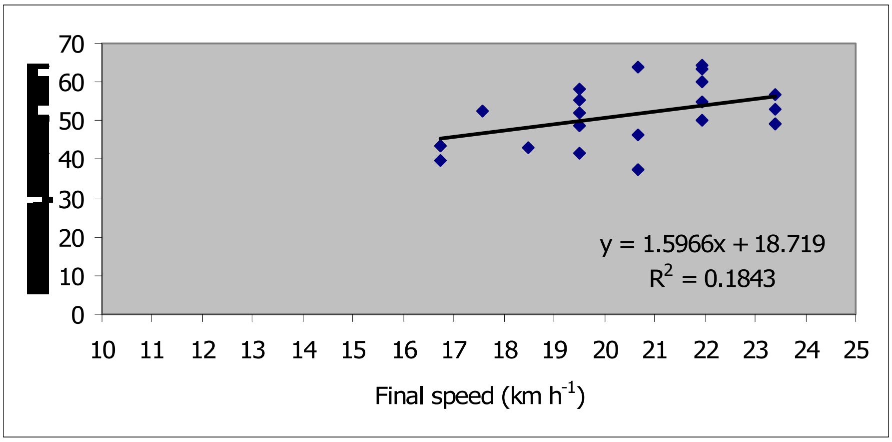
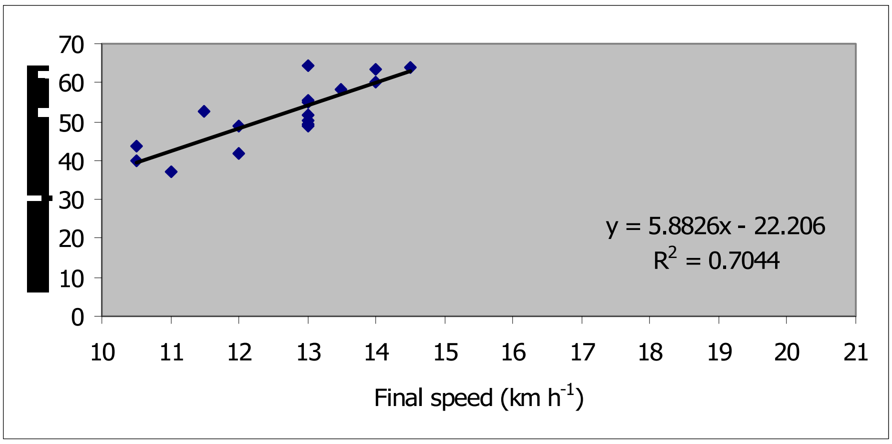


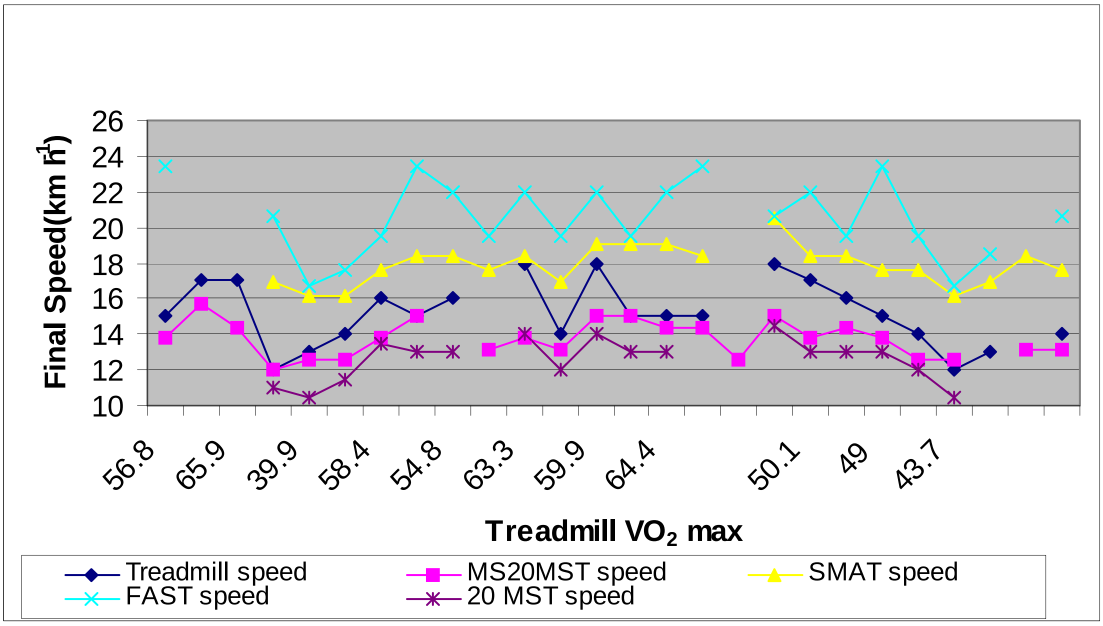
Figure 4.12 Treadmill VO_2 max as a Function of Speed in the 20 MST



From the above figures, the treadmill and the 20 MST have similar R^2 (R^2=0.7027 and R^2= 0.7044 respectively) indicating that 70.44 % and 70.27 % of the variance can be explained, again demonstrating the validity of the prediction equation of the 20 MST. Among the field ice-skating tests MS20MST and the SMAT (R^2=0.5473 and R^2=0.5304 respectively) showed similar validity where 54.73 % and 53.04 % of the variance can be explained by the respective regression equations. Regarding the validity of the FAST, the FAST showed a lower R^2=0.1843, where only 18.43 % of the variance can be explained by the regression equation. The FAST may thus be less valid because, subjects have less control on how the subjects negotiate the change of direction at each end of the course (this is also not well standardized and specified in the protocol) and also because, the terminal point is less reliable in a test where the speed increases exponentially with time (as apposed to a linear increase) and a small difference in motivation could make a large difference in the final results of FAST which in turn negatively affects the correlation with treadmill $\dot{V}O_2$ max. Furthermore, the 20 MST is better correlated to the two other skating tests than to the FAST. These are interesting because they may indicate that anaerobic fitness also has an effect on the results of an aerobic test i.e. correlation is not perfect between $\dot{V}O_2$ max test results because other factors are also involved.

Finally, the treadmill $\dot{V}O_2$ max were regressed against the mean maximal speed in each test and are plotted on a single graph to compare the different tests. Refer to Figure 4.13.

Figure 4.13: Comparison of Treadmill Speed as a Function of $\dot{V}O_2$ max in All Tests

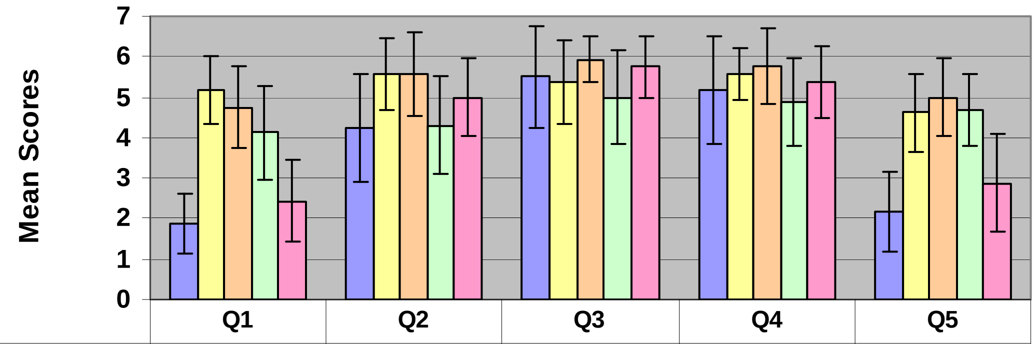


In summary, the administration of both the MS20MST and SMAT is inexpensive and does not require sophisticated equipment, only an audio recording of the test, compact disc player, measuring tape and a few cones, and many players can be tested simultaneously, in their practice/competition dress, without requiring players to change into other clothes or remove part of the kit (as in the FAST). Because of these abovementioned advantages and because of the higher correlations of the MS20MST and the SMAT, they are the preferable tests to use when assessing the aerobic fitness of adult male ice-hockey players. In concordance with the fourth aim of the study [to determine if these on ice skating tests are in effect better than the over-ground 20 m shuttle running test (Léger *et al.,* 1988)] it can be said that the 20 MST has once again proven to be a valid test of aerobic fitness can be used with confidence to predict the aerobic capacity of ice-hockey players, and is preferable over other running tests, and is the test of choice if ice testing cannot be conducted.

4.4. Qualitative analysis: Determining which test is rated by ice-hockey players as being best suited and the most functional using the Likert scale

The third aim of the study was to determine which test is rated by the players as being the best suited and most functional test. For this purpose a seven-point Likert scale was used to evaluate five different aspects of each test. Players answered each question by giving a rating of between one and seven, one being the lowest possible score and seven being the highest possible score (refer to Appendix K). For all questions, the higher the score, the better the result, indicating greater similarity between the test and an ice-hockey game, and greater suitability of the tests to assess aerobic fitness in adult ice-hockey players. An overview comparison of the five questions, in the five tests is shown in Figure 4.14. There appears to be a trend where the running tests generally score lower than the skating tests, indicating a subjective need for skating tests to assess aerobic fitness in adult ice-hockey players.

Figure 4.14: Comparison of Scores Obtained on the Likert Resemblance Scale (1-7) During Different Tests



	Q1	Q2	Q3	Q4	Q5
Treadmill	1.88	4.25	5.50	5.19	2.19
MS20MST	5.19	5.56	5.38	5.56	4.63
SMAT	4.75	5.56	5.94	5.75	5.00
FAST	4.13	4.31	5.00	4.88	4.69
20 MST	2.44	5.00	5.75	5.38	2.88

Tests

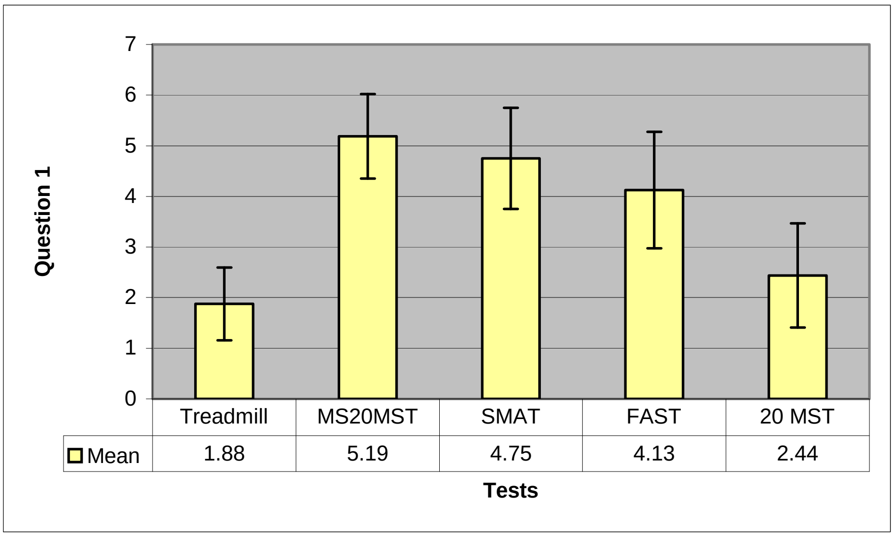
Q1	Similarity of basic skating skills (not puck handling) of the test compared to those of a hockey game
Q2	Resemblance between maximal intensity of the test & maximal intensity of a hockey game
Q3	How is the test suited to evaluate aerobic fitness of hockey players?
Q4	How is the test suited to evaluate overall fitness (including muscular & cardiovascular fitness) of hockey players?
Q5	How is the test suited to evaluate overall hockey ability (fitness & skating skills) of hockey players?

Note: Pairs of values joined by a vertical bar are different (p<0.05)

Question 1: Similarity of basic skating skills (not puck handling) of the test compared to those of a hockey game

The mean score obtained for question one in all five tests as well as the significant differences are represented in Figure 4.15. Both running tests yielded lower ratings than the three skating tests. Logically the laboratory treadmill test was rated as being the least specific of all the tests because it was conducted in a laboratory environment and the modality was running and not skating. Any type of skating would be more specific to the hockey player than any running protocol. Within the skating tests, FAST scores were lower than the MS20MST and SMAT scores. The MS20MST and SMAT obtained the highest subjective rating of test similarity with regard to basic skating skill as compared to the game of ice-hockey, and are the best tests to mimic skating skill. The 20 MST is however more specific for ice-hockey than treadmill running as it is a field test and the nature of the test is stop-and-go, which is similar to hockey, even though it is not skating. The higher rating of the MS20MST and SMAT tests is due to the fact that they are skating tests, and have stop-and-go nature (which is similar to the game of ice-hockey). The FAST was rated more specific than the two running tests (because it is skating), but not as specific as the two skating tests (because it is continuous and curvilinear), which may in fact be more appropriate for speed skating and figure skating than ice-hockey.

Figure 4.15: Mean Rating For Similarity of Basic Skating Skills of the Different Tests as Compared to the Game of Ice-Hockey (n=16)

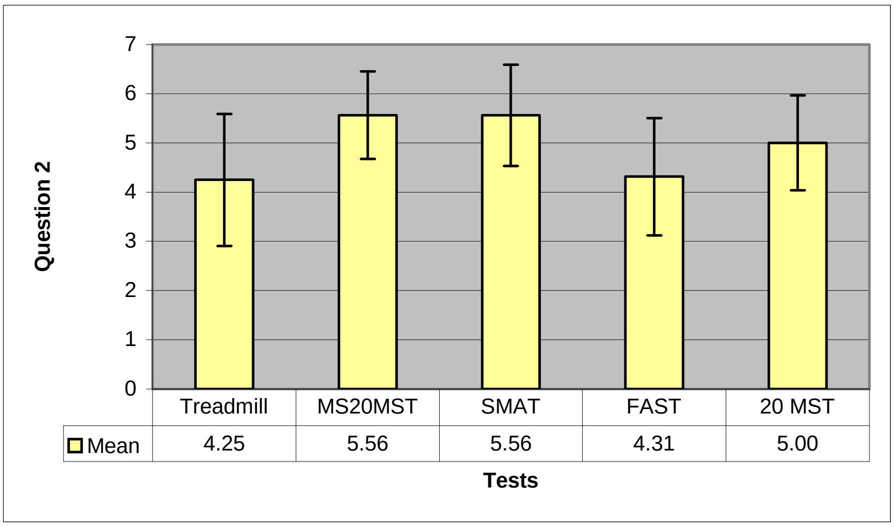


When subjects rated the similarity of the skating skills required by the test as compared to those required during a hockey game (excluding puck handling), there were statistically significant differences between the scores obtained between the treadmill and the MS20MST (p≤0.0001), treadmill and the SMAT (p≤0.0001), and the treadmill and the FAST (p≤0.0001). Similarly, the 20 MST had highly significant differences with all three skating tests (MS20MST, SMAT, and FAST) (p≤0.0001). The MS20MST also differed significantly with the FAST (p≤0.05).

Question 2: Resemblance between maximal intensity of the test & maximal intensity of a hockey game

Mean responses to question two are presented in Figure 4.16. SMAT and MS20MST again obtained the highest subjective rating with regard to the similarity of the intensity of test to the intensity of the ice-hockey game followed by the 20 MST, and then FAST and the treadmill.

Figure 4.16 Mean Rating of Similarity of Intensity of the Different Tests as Compared to the Game of Ice-Hockey (n=16)

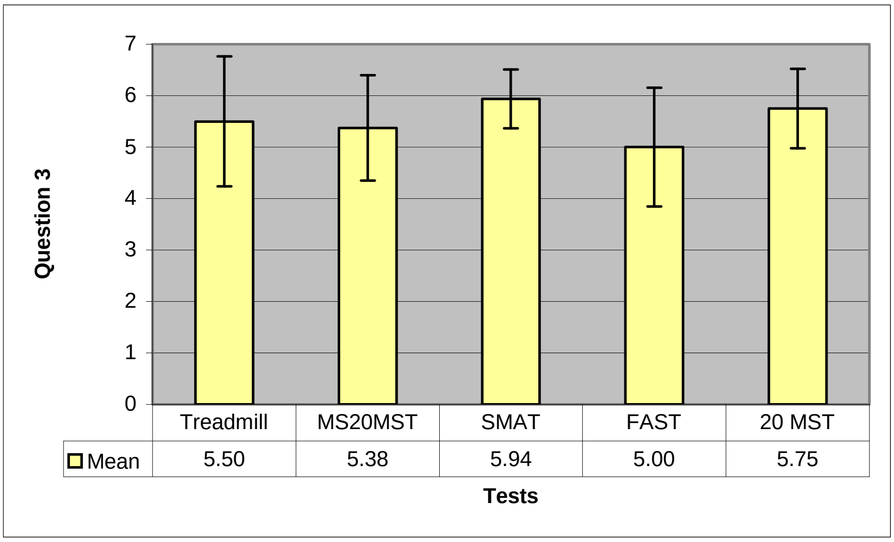


There were significant differences between the treadmill and the MS20MST (p≤0.01) and between the treadmill and the SMAT (p≤0.01). There were also significant differences between the FAST and MS20MST (p≤0.01), as well as between the FAST and SMAT (p≤0.01). This is to be expected as the MS20MST and SMAT are similar in nature.

Question 3: How is the test suited to evaluate aerobic fitness of hockey players?

The mean responses to question three in all tests is shown in Figure 4.17. Three out of five tests (MS20MST, FAST, and treadmill) had very similar scores with regard to subjective suitability of the tests to evaluate aerobic fitness in ice-hockey players. The FAST obtained the lowest suitability rating, indicating that subjects felt that the FAST was not as suited to assessing aerobic fitness as the other tests. The only statistically significant difference between the rating of suitability for assessing aerobic fitness occurred between the SMAT and FAST (p≤0.05).

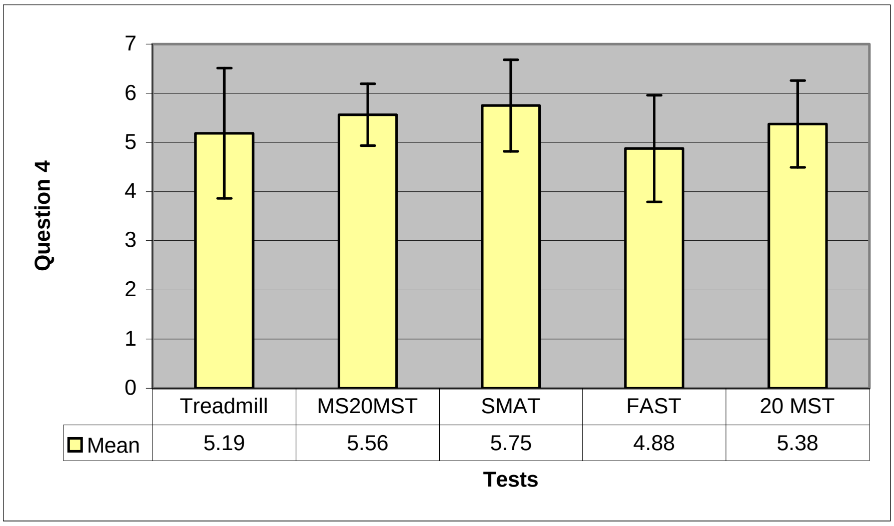
Figure 4.17: Mean Rating of Suitability of the Different Tests to Evaluate Aerobic Fitness of Hockey Players (n=16)



Question 4: How is the test suited to evaluate overall fitness (including muscular & cardiovascular fitness) of hockey players?

The mean responses to question four in all tests are shown in Figure 4.18. The SMAT and MS20MST obtained similar scores with regard to suitability to evaluate overall fitness in ice-hockey players, followed by a lower rating of the 20 MST, treadmill and FAST. The only statistically significant difference occurred between the SMAT and FAST ($p \leq 0.05$).

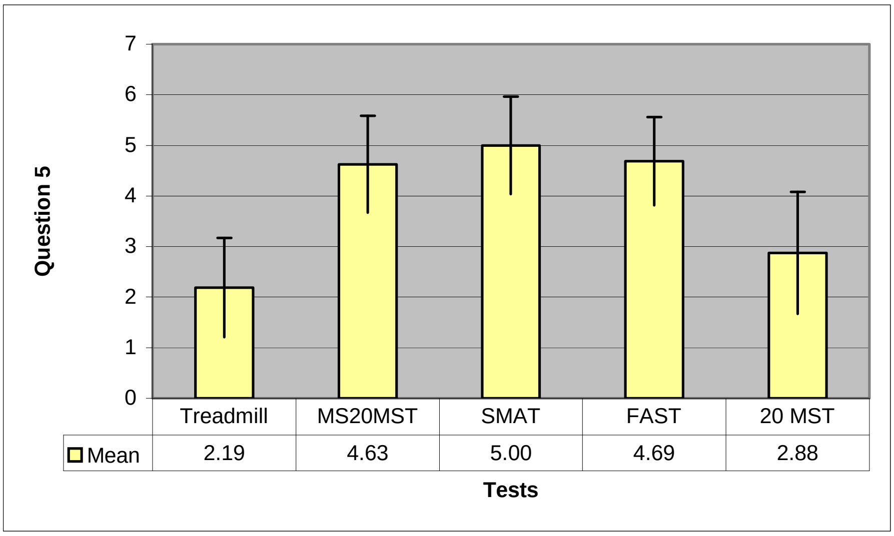
Figure 4.18: Mean Ratings With Regard to Suitability of Each Test to Evaluate Overall Fitness (Including Muscular & Cardiovascular Fitness) of Hockey Players (n=16)



Question 5: How is the test suited to evaluate overall hockey ability (fitness & skating skills) of hockey players?

Mean responses to question five in all tests is represented in Figure 4.19. The treadmill and the 20 MST yield lower ($p \leq 0.0001$) scores than the three skating tests while the skating tests were not significantly different from each other.

Figure 4.19: Mean Rating of Suitability of Tests to Evaluate Overall Fitness in Ice-Hockey Players (n=16)



In summary, the qualitative analysis reveals that the skating tests (MS20MST and SMAT) generally scored higher with regards to similarity to the game of ice-hockey, as well as suitability to assess aerobic and overall fitness in ice-hockey players. This clearly demonstrates the need for on-ice skating tests for the assessment of aerobic fitness in ice-hockey. The FAST however, seems to be the least preferable of the skating tests, and sometimes even less preferable than the 20 MST.

Correlations among Q1-5

Q1

Correlation coefficients are presented in Table 4.10. There was a significant correlation between the mean score for question one between the treadmill and the 20 MST (r=0.53), which is to be expected since they are both running tests, and between the treadmill and the FAST (r=0.59) (they also had similar RPE values). There was also a significant correlation between FAST and the 20 MST (r=0.68), which is unexpected.

Table 4.10: Correlations of Question 1 Values

Correlation Matrix					
	Treadmill	**MS20MST**	**SMAT**	**Fast**	**20MST**
Treadmill	1	-0.07	0.05	0.59*	0.53*
MS20MST		1	0.46	0.11	0.13
SMAT			1	0.26	0.31
FAST				1	0.68*
20MST					1

* Correlation is significant at the 0.05 level

Q2

Correlation coefficients are presented in Table 4.11. The only significant correlation with regard to similarity of intensity among the test was between the treadmill and 20 MST (r=0.57), this is to be expected since the modality of the tests are the same (both running), and probably equally unfamiliar to the subjects as apposed to skating.

Table 4.11: Correlations of Question 2 Values

Correlation Matrix					
	Treadmill	**MS20MST**	**SMAT**	**Fast**	**20MST**
Treadmill	1	0.26	0.47	-0.01	0.57*
MS20MST		1	0.21	-0.18	0.46
SMAT			1	-0.04	0.47
FAST				1	-0.23
20MST					1

* Correlation is significant at the 0.05 level

Q3

There were no significant correlations among the five tests with regard to suitability for assessing aerobic fitness.

Q4

Correlation coefficients are presented in Table 4.12. The only correlations were between the treadmill and the 20 MST (r=0.50), and between the MS20MST and the 20 MST (r=0.55).

Table 4.12: Correlations of Question 4 Values

Correlation Matrix					
	Treadmill	**MS20MST**	**SMAT**	**Fast**	**20MST**
Treadmill	1	0.26	0.36	0.34	0.50*
MS20MST		1	0.37	0.21	0.55*
SMAT			1	0.30	0.45
FAST				1	0.19
20MST					1

* Correlation is significant at the 0.05 level

Q5

Correlation coefficients are presented in Table 4.13. The only significant correlation was a significant correlation between the treadmill and 20MST (r=0.75) (again probably because they are both running tests).

Table 4.13: Correlations of Question 5 Values

Correlation Matrix					
	Treadmill	**MS20MST**	**SMAT**	**Fast**	**20MST**
Treadmill	1	0.15	0.49	0.38	0.75*
MS20MST		1	0.36	0.25	0.01
SMAT			1	0.47	0.47
FAST				1	0.09
20MST					1

* Correlation is significant at the 0.05 level

In summary, the qualitative analysis reveals that the skating tests consistently scored higher with regards to similarity to the game of ice-hockey, as well as suitability to assess aerobic and overall fitness in ice-hockey players. This clearly demonstrates the need for on-ice skating tests for the assessment of aerobic fitness in ice-hockey.

4.5. General Discussion

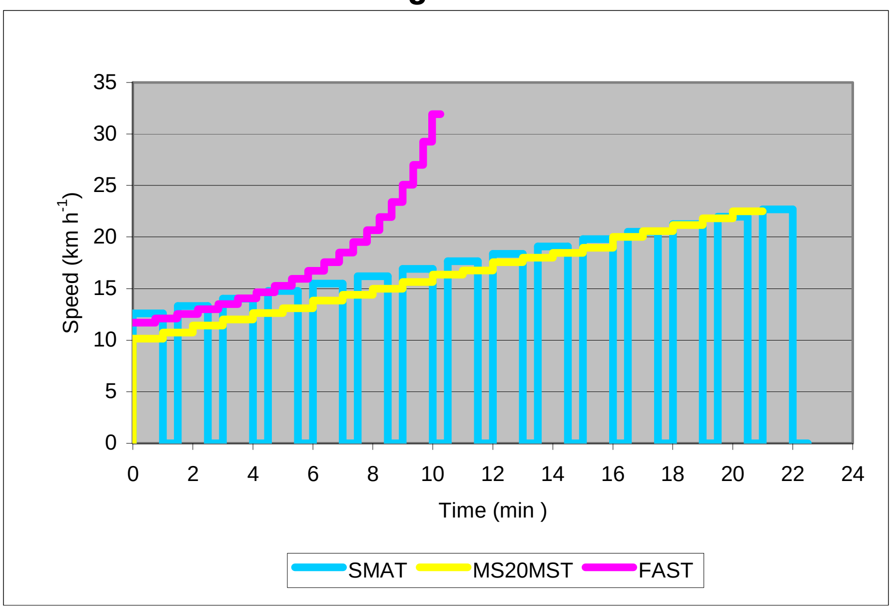
The validation of the three new ice-skating field tests has been done as follows:

1. with medium to large groups of subjects, with a wide range in maximal speed and/or $\dot{V}O_2$ max values (fitness levels),
2. with homogeneous skating ability (stop, start, turning, and cross-over skating)
3. with subjects of the same gender (males), age (adults), and specialty category (hockey), and
4. with equipment specific to the specialty and test (full equipment for MS20MST and SMAT, and only helmet, stick and gloves for the FAST).

Final Speed

The progression of speed in the three skating protocols is presented in Figure 4.20.

Figure 4.20: Progression of Speed in the Three ice-Skating Protocols



Skating velocity can be termed maximal aerobic skating velocity (MASV) or the functional maximal aerobic power (FMAP), and along with $\dot{V}O_2$ max, can be considered the "performance score" that can serve as a guideline for monitoring individual training intensity and a means to evaluate the aerobic effect of a particular program (Leone *et al.,* 2007). However, this is true only if subjects reach steady state $\dot{V}O_2$ at each stage which is probably not the case in all the protocols used in this study, due to the differences in maximal speed obtained in the MS20MST and SMAT). Léger, Seliger & Bassard (1979) reported that hockey players had lower coefficients of variation for the maximal skating speeds (3.4-4.8%) than for their $\dot{V}O_2$ max (11.0-15.1%). The MS20MST had the lowest maximal skating speed, and although this correlated with the treadmill speed, it is questionable whether this is favourable. Although the MS20MST is specific for ice-hockey, with it's frequent stop and go, the distance of the test (shorter distance than SMAT, therefore requiring more stop-and-go), causes rapid muscular fatigue, and limits subjects from attaining higher maximal speed. The nature of the task (skating) must be specific to the sport, but must not be done at the expense of the obtained score (final velocity or $\dot{V}O_2$ max). Thus, with regards to maximal speed, the SMAT allows higher maximal speed, while maintaining a ice-hockey specific nature.

Heart rate

Heart rate has been shown to be a good indicator of estimating energy expenditure in hockey (Boyle, Mahone & Wallace, 1994). Petrella, *et al.* (2005) however, state that FAST-HR was less important in the estimation of aerobic capacity with the FAST; in fact, they showed it to be unreliable. In the development of the equation for the MS20MST in this study, height, weight, and duration were less important that final speed of the test. In fact final speed was the only significant predictor.

Léger, Seliger & Bassard (1979) demonstrated lower maximal heart rates on-ice for both hockey players and runners (10 beats min^{-1}), compared to the treadmill test. Vergès, Flore & Favre-Juvin (2003) also found a significant difference in heart rate during laboratory treadmill running (195.3±6.8 beats min^{-1}) and field roller skiing (190.4±5.6 beats min^{-1}), but not blood lactate concentration. In the present study, the same trend but with smaller magnitde was observed, where all four field test demonstrated lower HR_{max} values than the laboratory treadmill running test. Petrella (2006) found similar maximum HR during the FAST and treadmill test (190 beats min^{-1} in both tests). Since maximal lactate was lower during FAST and the treadmill test (see next section), we cannot exclude the possibility that hockey players of this study did not push themselves to the same extent during those tests explaining why HR was not higher during the treadmill test in this study compared to other ones. Similarly, Petrella (2006) found lactate values after their test (next section) to be higher than those reported in this study, indicating that they may have been able to push their subjects more than the subjects in this study (or the subjects were more motivated in that study) and explaining their similar maximal HR for the treadmill test and the FAST.

Lactate

During heavy dynamic exercise extracellular lactate can increase from 1.3 mmol L^{-1} to more than 13 mmol L^{-1} (ACSM, 2006b). The mean maximal lactate among the five tests in this study was 10.4 mmol L^{-1}, and is considered to be high, indicating maximal effort. Green *et al.* (1976) found that values of blood lactate in Canadian university players were highest during the first and second periods (mean 8.7 and 7.3 mmol L^{-1}, respectively) then declined during the third period (mean 4.9 mmol L^{-1}). The blood lactate in this study, is higher (10.4 mmol L^{-1}) than the lactate measured at the end of each period of the hockey game, as reported by Houston & Green (1976), to be in excess of 5 mmol L^{-1} and similar to the ~12 mmol L^{-1} that has been observed after one period of play reported by Snyder & Foster (1994). With time particularly with active recovery on ice and passive recovery on the bench, oxidative metabolism gets rid of lactate as is the common case during prolonged continuous exercise. Values reported by Snyder and Foster are however puzzling. On the other hand, with 14 males aged 21.73± 0.88 years, accumulated blood lactate concentration was 12.1±2.91 mmol L^{-1} after the FAST (Petrella, 2006). This is higher than the maximum lactate measured five minutes after completing the FAST in this study (n=16, 9.19±2.97 mmol L^{-1}). Maybe they were able to motivate their players more than subjects in this study. Green (1978) measured blood lactate levels of 10.9±1.2 mmol L^{-1} following 30 minutes and 13.3±0.6 mmol L^{-1} following 60 minutes of intermittent exercise. The blood lactate measured following the only intermittent test in this study (SMAT) was similar (12.1 mmol L^{-1}) than that reported by Green (1978).

The MS20MST and the SMAT both resulted in higher lactate values than both the treadmill and the 20 MST, indicating a higher anaerobic contribution in both the MS20MST and the SMAT, as compared to the FAST and the running tests. This indicates that the nature of the MS20MST and the SMAT are more hockey specific than the other tests. Although the subjects in this study were ice-hockey players, the nature of the FAST may make the test more suitable to speed skating or figure skating, rather than ice-hockey. This supports the notion of testing players in their training environment in a "competition simulated" manner.

$\dot{V}O_2$ max

The assessment of aerobic capacity is a fundamental measurement in the field of exercise physiology and provides useful information for exercise prescription, disease risk assessment, and monitoring the effectiveness of training programs (ACSM, 2006). Having a well trained aerobic system in ice-hockey will be beneficial for numerous reasons. Although high intensity is required during a game, the aerobic system plays an important role, simply due to the total duration of a game (Green, 1987). Green (1979) suggested that optimal performance in ice-hockey depends on maximal involvement of the aerobic system for the ATP resynthesis while maintaining the glycolytic involvement, and that the tempo of the game is, in large part, determined by the potential of the aerobic system (Green, 1976). Recovery is also positively influenced by a well trained aerobic system, not only between the bursts of high intensity during a game, but also between subsequent games (Twist & Rhodes, 1993a; Bracko, 2001). Arnett (1996) states that the critical measure specific to ice-hockey is the ability of the oxidative energy system to replenish phosphocreatine and ATP concentrations, in turn allowing high intensity performance to be repeated. Therefore, the effectiveness of the oxidative energy system to replenish energy stores during the rest phase is vital for success in ice-hockey.

Furthermore, by having a well trained aerobic system, the fatigue experienced during a game is reduced, allowing the player to execute skills more accurately (technical component), since hockey demands precise coordination of many muscle groups, excessive increases in lactate would interfere with the execution of hockey skills (Montgomery, 1988). With less perceived fatigue, players are able to make decisions more quickly, with improved reaction time (tactical component). From a psychological point of view, perceived exertion will be reduced, thereby improving motivation and concentration. Physically, there is reduced injury risk, and overall improved performance.

$\dot{V}O_2$ max is important in hockey, as when two players have the same efficiency, the one who has the greatest $\dot{V}O_2$ max will be the best one to perform aerobic skating (Léger, Seliger & Bassard, 1979). The mean $\dot{V}O_2$ max score across tests was 51.28 ml kg^{-1} min^{-1}. This value is comparable to that reported in the literature (44.4-66.5 ml kg^{-1} min^{-1}, refer to Appendix D).

According to Snyder & Foster (1994) ice-hockey players, even more so than speed skaters, tend to have relatively ordinary aerobic abilities. Values for $\dot{V}O_2$ max ranging from 53-57 ml kg^{-1} min^{-1} have been reported for ice-hockey players who completed treadmill running tests, which is comparable to the mean $\dot{V}O_2$ max reported for treadmill running during this study (52.74 ml kg^{-1} min^{-1}). It has been reported that ice-hockey players had a mean $\dot{V}O_2$ max of 57.2 ml kg^{-1} min^{-1} during running tests, 53.4 ml kg^{-1} min^{-1} during cycling tests, and 55.5 ml kg^{-1} min^{-1} ml kg^{-1} min^{-1} during skating tests (Snyder & Foster, 1994).

In 1976 Simard demonstrated that the best skaters had lower $\dot{V}O_2$ max in the laboratory, showing that they were much more efficient on the ice and demonstrating that laboratory testing can yield inaccurate results. This further illustrates the advantage of testing players in their training environment to obtain accurate results. Even with similar $\dot{V}O_2$ max and lactate values on the treadmill and on the ice, a skating test is still preferable for hockey players, and treadmill testing of a hockey player who is a poor skater, but a good runner might give imprecise information as to his ability to perform aerobic skating (Léger, Seliger & Bassard*,* 1979). Leone *et al.* (2007) state that sport specific training and testing is recognized as essential to maximize the performance in elite athletes. Skating movements are not mirrored by either bicycle or treadmill tests and therefore may not adequately reflect the specific aerobic power developed by ice-hockey players (Nobes *et al.,* 2003).

In an attempt to make the measurement of $\dot{V}O_2$ max more sport specific for ice-hockey, Dreger & Quinney (1999) used a skating treadmill protocol where subjects skated in their own hockey skates. The protocol was intermittent using 2 minutes of skating, followed by 2 minutes of rest. This, to some extent mirrors the intermittent nature of ice-hockey. This protocol can be criticized, because subjects were only wearing hockey skates, shorts and a t-shirt, thus eliminating the effect of added mass from wearing a full kit (as in practice and competition), and not carrying a stick. Secondly, Dreger &

Quinney (1999) used a protocol where the speed was self selected (14.4 to 16.0 km/h) and the elevation was increased by 2% at every stage. This might defeat the purpose of trying to develop a test and protocol that is sport specific, because hockey players never skate uphill, and this protocol alters the movement mechanics of skating and results may be negatively affected by muscular fatigue rather than cardiorespiratory fatigue. This increase in grade may be necessary due to the limited speed of the treadmill. Furthermore, the direction of skating on the skating treadmill cannot change, as in a game situation. Although the skating treadmill has advantages such as representing the skating movement, the increased resistance, however, may make it more appropriate for training than testing. When using the skating treadmill, it is also easier to control the speed and distance, which is more difficult to do during ice testing. Disadvantages however, include the high cost of such a piece of equipment, it is time consuming, and only one subject can be tested at a time. In the laboratory, there is also a lack of wind resistance, and a competitive environment, as well as a difference in temperature in the laboratory as compared to the ice arena.

Cycle ergometry, treadmill running and treadmill skating offer some variation of metabolically demanding exercise, but do not allow the participant to perform the same mechanics of skating on-ice (Petrella, 2006; Leone *et al.,* 2007). There are biomechanical complexities and increased energy demands during shuttle running compared to treadmill running, which may be attributed to differences in factors such as intensity, exercise mode, technique, and musculature employed between the two conditions (Flouris, Metsios & Koutedakis, 2005). If ice testing cannot be done, the 20 MST is preferable to laboratory testing, for reasons stated above.

In a previous attempt to measure the $\dot{V}O_2$ max values of ice-hockey players while subjects performed the on-ice skating 20 MST (original version, Léger *et al.*, 1988), as directly determined by the Aerosport$_{TM}$ portable gas analyser,Kuisis & van Heerden (1999) reported lower $\dot{V}O_2$ max values

(43.7±6.6 ml kg^{-1} min^{-1}) than reported during this study (using the presently developed prediction equation) when subjects performed the MS20MST (52.27 ml kg^{-1} min^{-1}). Petrella (2006) determined the $\dot{V}O_2$ max of adult male ice-hockey players performing the FAST to be 53.97 ml kg^{-1} min^{-1}, subjects performing the FAST in this study obtained a mean $\dot{V}O_2$ max of 52.12 ml kg^{-1} min^{-1}.

Léger, Seliger & Bassard (1979) found no difference between the $\dot{V}O_2$ max of ice-hockey players in three ice skating tests (20 m on-ice course with and without equipment, and 140 m oval on-ice course) and an incremental treadmill test. A study on speed skaters by Quirion *et al.* (1988) states that the effect of cold exposure above anaerobic threshold decreases the blood lactate concentration, increases the $\dot{V}O_2$ max, with no change in exercise time and power output. The influence of cold on muscular exercise varies according to many factors among which the most important are: the type of exercise, the intensity and duration of exercise, fatty tissue, presence or absence of cold wind, clothing, severity of cold, fluctuations in body temperature, and energy reserves. Maximal cardiorespiratory capacity is lower and submaximal strain increases when ambient working temperature decreases. This means that individual strain caused by a given submaximal workload may be significantly higher in cold as compared to thermo neutral environment due to cooling (Oksa *et al.,* 2004).

Full hockey equipment (kit) includes shoulder, elbow, and shin pads, hockey jersey, gloves, socks, pants, helmet, and stick. Subjects in this study were weighed in the laboratory wearing only running shorts, and then again in the ice arena wearing full kit, with skates and hockey stick, before the SMAT or MS20MST. A small sub sample of four subjects were also weighed wearing a tracksuit, helmet, stick, and gloves, as required for the FAST. The mean added mass when dressed in full kit was 9.9±2.2 kg, and the added mass for the FAST ranged between 3.2 and 7.3 kg (n=4). Although Léger, Seliger & Bassard (1979) state that equipment weight and design increase the cost of skating by 4.8 % and reduces the endurance time by 20.3 %, Leone *et al.* (2007) are of the opinion that hockey equipment has changed dramatically since then and that the effect of equipment, if any, today, is probable marginal, although tightness of some cloths may still impede the motion of skating. From the previously mentioned added mass in this study, one would surmise that $\dot{V}O_2$ was higher in the tests where subjects were dressed in full kit (MS20MST and SMAT), but according to the results, there was no significant difference among the $\dot{V}O_2$ max obtained in the five tests, despite differences in dress. In this study, there were however, significant differences among the five tests with regard to test duration, but other factors may explain this difference and it is unlikely that the test duration was affected by the added mass of partial- or full-kit.

Moreover, Léger, Seliger & Bassard (1979) state that the skated 20 MST with equipment more closely approximates the nature of skating seen in a game. Thus, an added advantage of both the MS20MST and the SMAT can both be performed on a regular arena ice surface with players wearing full hockey equipment, as in a game situation, thus proving to be very specific. The administration of both these tests is inexpensive and does not require sophisticated equipment, only an audio recording of the test, compact disc player, measuring tape and a few cones, and may players can be tested simultaneously, in their practice/competition dress, without requiring players to change into other clothes or remove part of the kit (as in the FAST).

The SMAT has one specific advantage over the other two skating tests, because it is intermittent. The SMAT has 30 second rest periods after each one minute stage, thus avoiding undue muscular fatigue or injury to the lower back as ice-hockey players rarely skate in forward flexion for longer than 30 seconds. This also ensures that the end of the test for each subject is principally related to cardiorespiratory energy system fatigue and not muscular fatigue (Leone *et al*, 2007). The ability to repeatedly perform very high intensity exercise seems to be more sport specific rather than the ability to produce a single effort or prolonged exercise (Psotta *et al.,* 2005).

Leone *et al.* (2007) found the correlation coefficient between the SMAT and the 20 MST to be rather modest (r=0.69 for boys and r=0.47 for girls), indicating that the 20 MST shared only 48.2% and 21.9% of the variance with the SMAT respectively. In this study, the SMAT was the skating test with the highest correlation with the 20 MST (r=0.87), followed by the MS20MST (r=0.83). The FAST was not significantly correlated with the 20 MST (r=0.46).

Arnet (1996) states that the results of aerobic power tests should be interpreted with caution if the objective is to evaluate the energy systems needed to succeed in ice-hockey, and suggested that the Reed Repeat Sprint Skate Test is more useful in identifying whether training has resulted in specific metabolic adaptations. From the results obtained in this study, it can be said that all of the field tests used were able to discriminate between players of different fitness levels, and accurately predict treadmill $\dot{V}O_2$ max, some more accurately (MS20MST, SMAT, 20 MST), than others (FAST), and ice-tests being preferable to running tests.

In conclusion it is emphasised that any of the three of the skating tests can be used to evaluate the aerobic capacity of experienced hockey players who have mastered their skating skills (and who can perform rapid deceleration and abrupt stops, especially for the MS20MST and SMAT; cornering and cross-overs for the FAST). These tests should, however, be used with caution in beginners as the lower mechanical efficiency of beginners or unskilled players may affect the precision of the estimation of the oxygen uptake.