SUMMARY
The purpose of this study was to compare the peak forces and impulse during the propulsive phase of the diagonal stride in cross-country skiing. Significant differences in impulse were found between on-snow and roller skiing but were not consistent between the right and left foot. Indeed, larger impulses were observed in roller skiing for the right foot, whereas the left foot yielded larger impulses while skiing on-snow. No significant differences were found in peak forces. Right and left differences may exist between on-snow and roller-skiing.

INTRODUCTION
Competitive Cross-Country skiing is a year-round sport. When the snow is gone, Dry-land training is critical in the development of the athlete’s technique, balance, musculature, and endurance. Although cycling and running may be included in a skiers’ training regimen, specificity of training must occur to develop peak performance [1]. Therefore, many athletes choose to train using roller-skis, shorter dry-land skis attached to wheels which are used to simulate the movements and muscle innervations of snow skiing.

This study focused on the diagonal stride used in the classic technique of cross-country skiing. The classic technique consists of five distinct phases: free gliding, free glide and pole contact, preloading for the kick phase, the kick phase, and the swing phase [2]. These phases are repeated in a cyclical motion, which is quantified in length as well as rate [3]. The propulsive phase occurs when enough weight is shifted to a single ski, compressing the wax pocket and allowing the skier to “kick” the weighted ski backward against the friction of the kick wax on the snow. The ultimate goal is to create a high static coefficient of friction under the weighted ski, while maintaining a low kinetic coefficient of friction under the non-weighted ski. The focus of diagonal stride investigations evaluated temporal characteristics (such as time of glide and recovery) compared to the propulsive phase at the elite level [4,5,6,7].

The diagonal stride in roller-skiing is similar to that of on-snow skiing, except that the athlete is always able to generate the friction necessary for the propulsive phase. Recent research in cross-country skiing used roller-skiing to allow the athletes to be tested on treadmills in a controlled environment [7, 8, 9, 10]. However, few studies have addressed the differences in kinetics that may exist between on-snow and roller-skiing during the “kick” phase of the diagonal stride. Therefore, the purpose of this study was to compare the peak force and propulsive impulse created by the skier during the “kick” phase under two different conditions: cross-country skiing on snow and rollerskiing on pavement.

METHODS
Subjects: Six male and three female experienced skiers (age = 20 ± 1.5 years, weight = 69.1 ± 7.6 kg) participated in this study. Subjects were recruited from the University of Minnesota Duluth Nordic Ski Club and the College of Saint-Scholastica Nordic Ski Team. Each subject was required to be experienced (3+ years) in the diagonal stride, and have previously trained with roller-skis. All subjects signed an informed consent in accordance with the University of Minnesota IRB procedures.

Instrumentation: Dynamic force data were collected using Pedar-X In-Shoe Dynamic Pressure System (Novel GmbH, Munich, Germany). Data collection of force data was done using instrumented insoles placed in the subject’s ski boots. A wireless setup was used to gather data while the subject performed the diagonal stride. Repeatability and reliability of this system had previously been tested by Putti et al. [11].

Procedures: The site used for on-snow data collection was a 20-meter section of an inclined hill (approximately 15% grade) at a local Nordic ski center. All recruited subjects skied on the same day to control for snow and weather conditions. Each subject warmed up and was fitted with insoles and a data pack (which allowed wireless data collection). The subjects skied the 20-m section of the track three (3) times. Three trials were recorded for each skier. To isolate the contribution of the weight shift in the “kick” phase, participants were asked to ski without poles. Each subject skied at a self-determined speed, usually at a moderate pace due to the increased focus needed to maintain balance and proper technique to create ski friction. The snow conditions were considered warm, with air temperature above the freezing point (+ 3 °C), yielding slow gliding conditions.

The same procedure was repeated on roller-skis using a section of road of similar grade. The subjects used the same ski boots on roller-skis as they had on skis, limiting the variability associated with the boot-insole interface.
RESULTS AND DISCUSSION
Right and left insoles were compared for each subject. Significant differences were found in impulses for both the right and left insoles (α = 0.05). Interestingly, the right impulse was greater while roller-skiing whereas the left impulse was greater on-snow. There was no significant difference in peak force for either foot (Table 1).

The purpose of this project was to compare peak forces and impulses while on-snow skiing and roller-skiing during the propulsive phase of the diagonal stride. To avoid additional variability of pole forces, the skiers were asked to ski without poles. While significant impulse differences were noted, the force-time curves during on-snow and roller-skiing were quite similar. However, there was a notable difference in cycle frequency between on-snow skiing and roller skiing for all subjects (Figure 1). In addition, the initial peak observed during on-snow skiing is barely noted during roller-skiing and of lesser magnitude. This may be due to the difficult conditions experienced during the on-snow portion of testing, where subjects, concerned about balance, quickly put the ski on the ground before applying the force necessary for the “kick” phase. The right and left differences between on-snow and roller-skiing were surprising to the investigators, and would necessitate further investigations into the right and left side dominance in skiers.

CONCLUSIONS
Cross country skiers may spend as much as 50% of training time on roller-skis during the dry-land season [1]. Therefore, it is important for athletes and coaches to understand the mechanical characteristics of roller-skiing and on-snow skiing in order to create and improve specific training regimens during the off-season. The results showed that on-snow and roller-skiing are mechanically similar, but that right-left dominance differences may exist when using skis versus roller-skis.

| Table 1: Descriptive data (Means ± SD; (*) denotes statistical significance at α = 0.05) |
|---------------------------------|-------------------------------------------------|
| **t-Ratio**                     | **Mean Values**                                |
| **On-Snow**                    | **Rollerski**                                  |
| Impulse- R (N.s)               | 2.377 * 496.5 ± 112.5                          | 591.0 ± 112.5 |
| Impulse- L (N.s)               | 2.303 * 505.6 ± 131.9                          | 398.3 ± 131.9 |
| Peak Force- R (N)              | 0.862 1221.0 ± 82.8                            | 1246.3 ± 82.8 |
| Peak Force- L (N)              | 1.134 1330.6 ± 176.0                           | 1258.9 ± 176.0 |

ACKNOWLEDGEMENTS
We would like to thank Snowflake Nordic Ski Center for the use of their facilities, and Cory Speaker for equipment and technical assistance.

REFERENCES