Analysis of Kinetic and kinematic data from instrumented outrigger-skis of an elite Paralympic alpine skier: a pilot study

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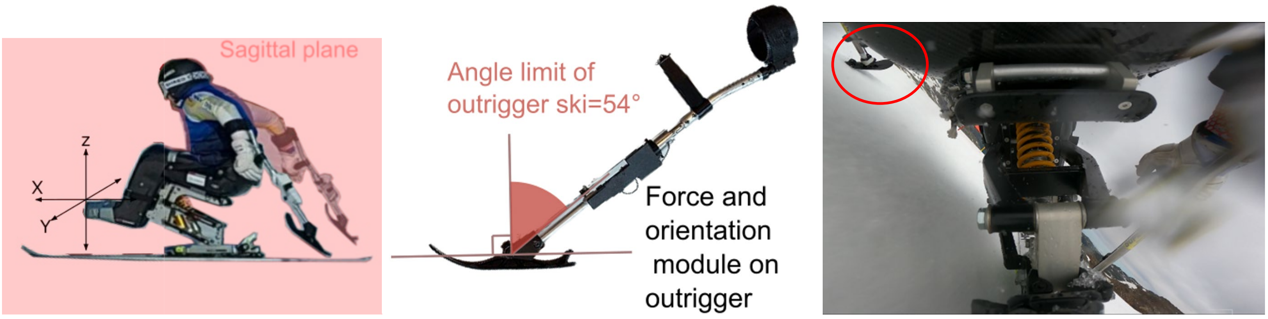
This study uses a novel sensor platform using force orientation to describe outrigger-skis kinetics and kinematics during Paralympic alpine giant slalom sit-skiing. Both outriggers-skis orientation and force data are translated into the sit-ski-coordinate system to calculate the sum of forces along each axis, describing a top-level athlete's kinetics, style, and technique. Paralympic alpine is an evolving sport in terms of research and participating athletes and includes several classification groups (LW 1-9, LW 10-12, and B 1-3) [1] to ensure fair competition. In the LW 10-12 class with leg impairments, the athletes use sit-ski/monoski with a shock-absorber to reduce vibrations [2,3]. In alpine skiing, the goal is to go as fast as possible down the slope, and by analyzing kinematics and kinetics [4], the skiing equipment and technique can improve performance. To assist the athlete using sit-skis/monoskis, poles with skis attached, called outrigger-skis, help the athlete maintain balance. The outrigger-skis are classified into two main groups: fixed outrigger-skis and flip outrigger-skis, which the athletes usually prefer [5]. The flip-ski type enables the athlete to release the ski by pulling a string from a fixed double poling position to a position where the ski can follow the slope's surface. Research on alpine outrigger-skis used by top-level athletes will increase the understanding of the kinetics and kinematics at work and can be used for analysis, design, and technique resulting in a comprehensive understanding of the sport.

In alpine skiing, resistance and unnecessary braking affect the competitive time, and at the Paralympic level small margins might affect podium placements. Therefore, an experiment was conducted with a multiple gold medal Paralympic alpine sit-skier competing in the LW11 class, set in a giant slalom course at Hafjell, Norway. According to Norwegian legislation, the athlete was informed in writing and provided consent prior to the study. The coach had previously instructed the athlete to use the outrigger-skis as little as possible during cornering to reduce resistance, but did not know to what extent the outrigger-skis affected the run. A novel sensor system [6] captures kinetics and kinematics during different movements at 80Hz. The data is stored on SD cards using timestamps, synchronized by RF and post-processed in python. Two force and orientation modules using IMU's and axial loadcells are mounted on a pair of outrigger-skis (Fig. 1b), and an orientation module IMU, is mounted on the sit-ski (Fig. 1a). The orientation of the outrigger-skis is calculated in relation to the sagittal plane of the sit-ski, i.e., the plane dividing the sit-ski. Thus, measured forces and angles in the outrigger-skis are translated into the sit-ski coordinate system and presented relative to the sit-ski. The sensor outrigger-skis resemble the Superlite (Enabling Technologies, USA) outrigger-skis already used by the athlete and feature a flip-ski, weighing 2750 grams per pair while the Superlite custom titanium outriggers-skis weight 1680 grams per pair. Both outriggers are supplied with a maximum positive ski rotation of 54° relative to the sit-ski (Fig. 1b). While below the positive ski rotation of the outrigger skis, resistance is affected by the friction surface of Polyethylene [7]. However, when above 54° the ice screws used when double poling and the edge on the back of the ski adds to both resistance and unnecessary braking effect (Fig. 1c).



(a) (b) (c)

Fig. 1: a) Sagittal plane of the sit-ski and the coordinate system. b) Flip-type sensor outrigger-ski with the 54° rotation limitation. c) Outrigger-ski 90° relative to the sit-ski while collecting data, above 54° limitation.

Data from one of the trial runs were selected to describe the kinematics in Paralympic alpine giant slalom sit-skiing (Fig. 2). The third force-spike at 2.5seconds in Fig. 2a and 2b comes from the release of the outrigger-ski, which affects the loadcell. Fig. 2b shows the decomposed forces from the right outrigger-ski, and Fig. 2c the orientation of the right outrigger-ski both in the sit-ski coordinate system. As shown in Fig. 2, the release mechanism in the left pole failed during double poling and was released too early, as frequently happens, resulting in a peak force of 275N. The left outrigger-ski had ground contact 24% with an average force of 39.2N during contact, while the right outrigger-ski had ground contact 43% of the run with an average force of 23.2N during contact.

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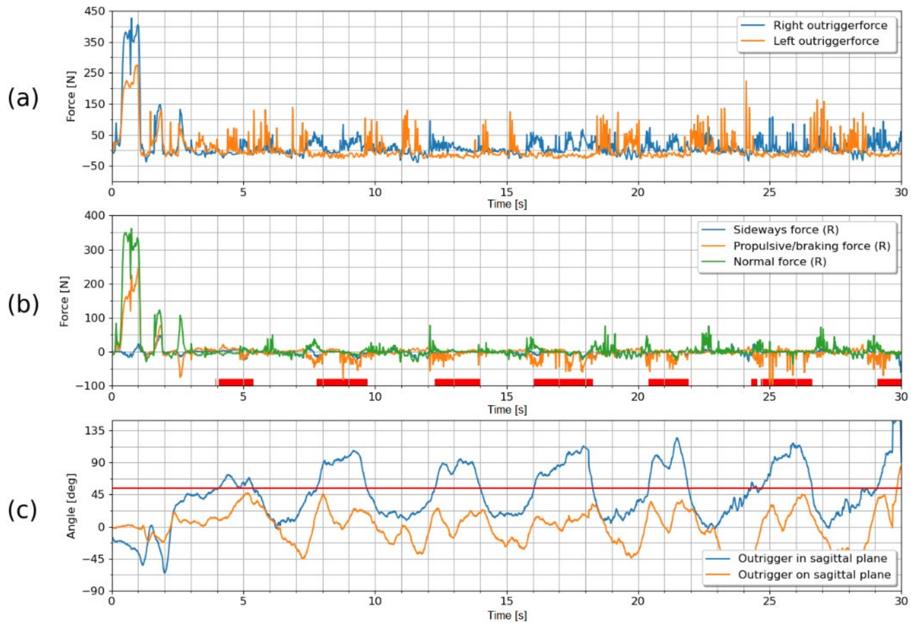

Fig. 2: a) Axial-force measurements from right and left outrigger. b) Decomposed forces of the right outrigger-ski relative to the sit-ski. Red rectangles shows where the outrigger angle is over the angle limit of the outrigger-ski. c) Orientation of the right outrigger-ski relative to the sagittal plane of the sit-ski with a red line at 54°.

Table 1: key data from the first 30 seconds of giant slalom

	Left outrigger	**Right outrigger**
Contact time	7.12s	12.9s
Average contact force	39.2N	23.2N
Contact time >54°	2.4s	5.6s
Average contact force >54°	40.1N	23.1N
Contact time <54°	5.5s	7.3s
Average contact force <54°	39.6N	23.2N

From the graph in Fig. 2a, the first stroke done by the athlete is visibly more extensive, starting from a still position with two sets of double poling to generate as much velocity as possible. In Paralympic alpine, the athlete turns by using the active pole to maintain balance, and a right turn is indicated by a high pole angle using the right-hand pole relative to the sit-ski. The difference in average contact time and force indicates either a difference in technique between left and right turns, or slope characteristics. The difference in weight between the normal outrigger-skis and sensor outrigger-skis could affect the results, and technology development and weight reduction could increase the accuracy in addition to adding bending moments to the system. While below the 54° limit, reduction in velocity could be calculated by combining the braking force and the normal force combined with the friction coefficient Polyethylene [7]. While above the 54° during hard cornering, the outrigger-skis no longer follow the surface, and all forces registered are assumed to slow the athlete down.

The results present the kinetics and kinematics in the outrigger-skis during a selected alpine run from a gold medal-winning athlete. The characteristic shows that the forces mainly occur when rapidly changing the angle on the sagittal plane. When not in contact with the ground or running straight, the outrigger-ski angle stayed close to 25° relative to the sit-ski. When cornering, the relative outrigger-ski angle where approximately 90°, way above the 54° limitation. The orientation module is used to calculate decomposed forces and angles in the sit-ski coordinate system, enabling a better understanding of Paralympic alpine outrigger-skis kinematics. A test with a elite Paralympic alpine skier was conducted and showed in this study, identifying losses due to friction and outrigger-skis design. The outrigger-skies are shown to add a relevant amount of braking effect when performing giant slalom, with a significant potential for improvement, laying the basis for further outrigger-ski development and analysis of style and technique applicable for athletes and coaches.

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