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**Research article**

# Automated Identification and Evaluation of Subtechniques in Classical-Style Roller Skiing

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**Abstract**

The aims of the present study were (1) the development of an automated system for identifying classical-style ski subtechniques using angular rate sensors, and (2) the determination of the relationships among skiing velocity, ski course conditions, and ski subtechniques using a global navigation satellite system (GNSS) and the developed automated identification system. In the first experiment, the performance of a male cross-country skier was used to develop an automated system for identifying classical-style ski subtechniques. In the second one, the performances of five male and five female college cross-country skiers were used to validate the developed identification system. Each subject wore inertial sensors on both wrists and both roller skis, a small video camera on the helmet, and a GNSS receiver. All subjects skied a 6,900-m roller ski course using the classical-style at their maximum speed. The adopted subtechniques were identified by the automated method based on the data obtained from the sensors, and also by visual count from a video recording of the same ski run. The results showed that the automated identification method could be definitively used to recognize various subtechniques. Specifically, the system correctly identified 9,307 subtechnique cycles out of a total of 9,444 counted visually, which indicated an accuracy of 98.5%. We also measured the skiing velocity and the course slope using the GNSS module. The data was then used to determine the subtechnique distributions as a function of the inclination and skiing velocity. It was observed that male and female skiers selected double poling below 6.7° and 5.5° uphill, respectively. In addition, male and female skiers selected diagonal stride above 0.7° and 2.5° uphill, and below 5.4 m/s and 4.5 m/s velocity, respectively. These results implied that the subtechnique distribution plot could be used to analyze the technical characteristics of each skier.

**Key words:** GPS/GNSS, cross-country skiing, inertial sensor, angular rate.

## Introduction

In competitive classical-style cross-country skiing, the participating skiers use several different subtechniques (Nilsson et al., 2004). The first of these is the diagonal stride (DS) technique, an uphill subtechnique executed in a diagonal fashion in which the arm push-off is performed together with the leg push-off on the contralateral side of the body. The second subtechnique is the kick double poling (KDP) technique, which is used on the flat and slight uphills. The arms are used in parallel together with one leg to push the body forward. The third subtechnique is the double poling (DP) technique, which is mainly used on flat terrain. In DP, the arms are used in parallel to push the body forward. Skiers chose different subtechniques depending on the terrain, snow conditions, and individual preferences. It was found that DS required the highest oxygen cost, with KDP inducing a 16% and DP a 26% lower oxygen cost compared to DS on flat terrain (Hoffman et al., 1990). In contrast, it was reported that the oxygen uptakes of DS and DP were similar on 7.1% grade terrain (Hoffman et al., 1994). These reports suggest that the energy cost of the classical-style subtechnique vary with the effects of the subtechniques and the terrain. In other words, the adopted subtechnique is one of the factors that determine the results of competitions. Moreover, measurement of the subtechnique and skiing velocity would provide information about the technical characteristics of skiers. Such information would assist the evaluation of the subtechnique selection and determination of the strong and weak subtechniques of a skier.

In several recent studies, a global navigation satellite system (GNSS) or global positioning system (GPS) was used to measure the skiers' position and velocity during cross-country skiing (Andersson et al., 2010; Bortlan et al., 2012; Sandbakk et al., 2013; 2014). Andersson et al. (2010) used a differential GNSS (DGNSS) to measure the skiing velocity during a skate-style cross-country sprint skiing, and used a video camera to identify the subtechniques of the skiers. Their findings showed that sprint skiing performance was primarily related to the uphill performance, better utilization of the Gear3 technique, and higher DP and Gear3 maximum velocities. Bortlan et al. (2012) also proposed a new methodology involving the use of a combination of a pole force sensor and GPS to evaluate the subtechnique distribution and the force exerted through the poles in the classical-style cross-country skiing. This method was used to identify DS with good accuracy based on the poling force phase, although it could not discriminate between DP and KDP. The results of the study showed that a skier tended to use DS to achieve maximal power below about 6 m/s skiing velocity and above 10% grade. The results of the foregoing studies suggest that data on the skiing velocity and course condition obtained by GPS/GNSS can be used in conjunction with the adopted subtechnique to analyze the technical characteristics of a skier.

Small and light inertial sensors have been recently used to identify the subtechniques because they do not disturb the movements of the skier. A microsensor unit consisting of a triaxial accelerometer, gyroscope sensor, GPS device, and magnetometer was used to identify the subtechniques of both classical and skating-styles (Marsland et al., 2012). The unit can be used to visually observe the patterns of the cyclical movements of the

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subtechniques. The difference between the hip movements of Gear2 and Gear3 was shown using a triaxial accelerometer placed on the sacrum (Myklebust et al., 2013). These studies demonstrated the possibility of using inertial sensors to identify subtechniques. A new algorithm was developed for identifying skating-style subtechniques using four accelerometers placed on the poles and ski boots (Myklebust et al., 2011). The algorithm used the time of the ski/pole hits and leaves to classify the subtechniques. The results showed that the pole hits, ski hits, and pole leaves were detected with high accuracies of 99, 99, and 95%, respectively. However, the detection accuracy of the ski leaves was 77% because of the complex movement of the ski during V2. Moreover, the algorithm requires many thresholds for detecting the timing and for the subtechnique classification procedures. The values were fitted for the subjects using the data collected during the study.

The various subtechniques of classical-style cross-country skiing have different arm and leg movement patterns. Therefore, the angular rates of the arms and legs are considered to be particularly effective for identifying the subtechniques. Moreover, GNSS/GPS can be used to estimate the skiing velocity and course grade, and automated of subtechnique identification is a powerful tool that can be used to analyze the technical characteristics of skiers in cross-country skiing. Hence, the aims of the present study were (1) the development of an automated subtechnique identification system using angular rate sensors, and (2) the examination of the relationships among the skiing velocity, course conditions, and subtechniques using a DGNSS and an automated identification system.

## Methods

### Development of automated identification system

### Pre-experiment

A pre-experiment was conducted to develop an automated identification system of classical-style subtechniques. A male cross-country skier (age: 34 yrs.; height: 1.75 m; weight: 63 kg) participated in this study. The subject provided informed consent prior to the experiments. The subject used his own racing poles (TRIAC 1.0, Swix Sport AS, Norway) and roller skis (MC700C, Marwe Roller Skis, Finland) during the test. Four inertial sensors (LP-WS0901, accelerometer: ±50 G; gyroscope: ±1500 deg/s, Logical Product Corp., Japan) were used in this study. The sensors were attached to both wrists of the subject and to both of his roller skis (Figure 1). These sensors measured the angular velocities of the long axis at the forearm and of the roller ski on the sagittal plane. The pre-experiment was conducted on an asphaltic road. The test was conducted at submaximal velocity using all the classical-style subtechniques (DS, KDP, and DP). A total of 426 cycles, which included all subtechniques, were recorded. Angular velocities were sampled at a rate of 100 Hz and stored by each sensor. The subject was videotaped using a digital video camera (HDR-CX700C, Sony, Japan) to identify the subtechniques employed.

### Definition of a cycle

The obtained data were processed offline using MATLAB (The MathWorks, Inc., USA). All raw angular velocities obtained by sensors were smoothed using a Butterworth low-pass digital filter with a cutoff frequency of 3 Hz.

The angular velocity of the right forearm corresponding to the mediolateral axis was used to define a cycle. First, the typical angular velocity of a single cycle was obtained by measuring from one local maximum to the next one using the pilot experiment. The cross-correlation (Li and Caldwell, 1999) between the typical single cycle and the angular velocity of the subject's right forearm was then determined. Local maximum points with coefficients higher than 0.25 were identified using the time series of the coefficient of cross-correlation. Minimum values of the coefficient of cross-correlation between adjacent local minimums were used as the start and end points of the one cycle.

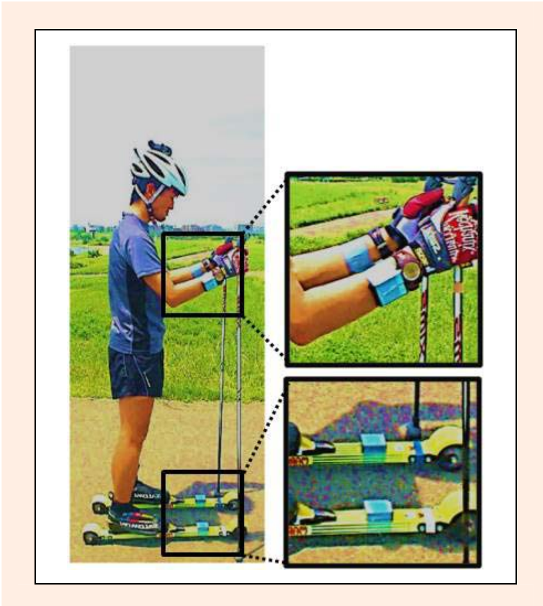

**Figure 1. Location of inertial sensors on wrists and roller skis.**

### Detection of diagonal stride

Only the DS technique shows an antiphase movement in both upper limbs, unlike KDP and DP. Therefore, the cross-correlation (Li and Caldwell, 1999) between the angular velocities of the right and left wrists in the sagittal plane was used to classify DS in one cycle. If the coefficient of the cross-correlation was under -0.25, this cycle was detected as DS (Figure 2).

### Detection of kick double-poling

In both the KDP and DP techniques, the upper limbs show a symmetric movement in the sagittal plane. Thus, the cross-correlation was calculated as stated in the previous section. If the cross-correlation coefficient was over 0.25, this cycle was categorized as KDP or DP. Then, any kick motion was identified using the pitch angular velocities of both roller skis. In the kick motion, the pitch angular velocity of the roller ski had absolute minimum and maximum values of over 100 deg/s before the time of

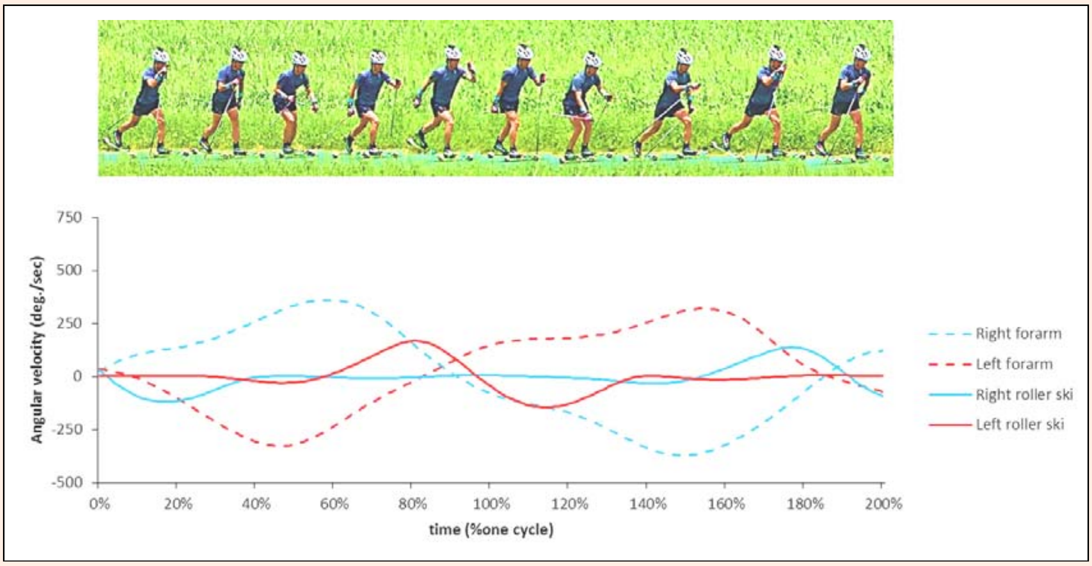


**Figure 2. Angular velocities of forearms and roller skis in the sagittal plane during the diagonal stride technique. The two forearms showed an antiphase movement.**

the maximum wrist angular velocity in the sagittal plane (see Figure 3). In general, a cross-country skier consecutively uses KDP and alternate legs (see Figure 3). Hence, KDP was further defined as a cycle with kick motion whose adjacent cycle also included a kick motion with the other leg.

### Detection of double-poling

DP was defined as occurring when the arms moved symmetrically without a kick movement. In addition, any cycle with a kick motion, but with preceding or following cycles that did not include a kick motion was considered to be DP in this study (Figure 4).

### Validation experiment

### Subjects

Ten college cross-country skiers, 5 female and 5 male, belonging to the Ski Association of Japan participated in this study. The anthropometric and physical performance characteristics of the subjects are presented in Table 1. The FIS points of the subjects were between 39.2 and 152.9 and between 68.3 and no points for men and women, respectively. The subjects had no known disorders that would influence their skiing performance. Before the experiment, the purpose and procedures of this study were explained to each subject, and written informed consents were obtained from all of them. The experimental procedure was approved by the Ethical Committee of the Japan Institute of Sports Sciences.

### Protocol

In the experiment, all subjects used their own racing poles and racing roller skis (MC700C, Marwe Roller Skis, Finland). As in the pre-experiment, four sensors were

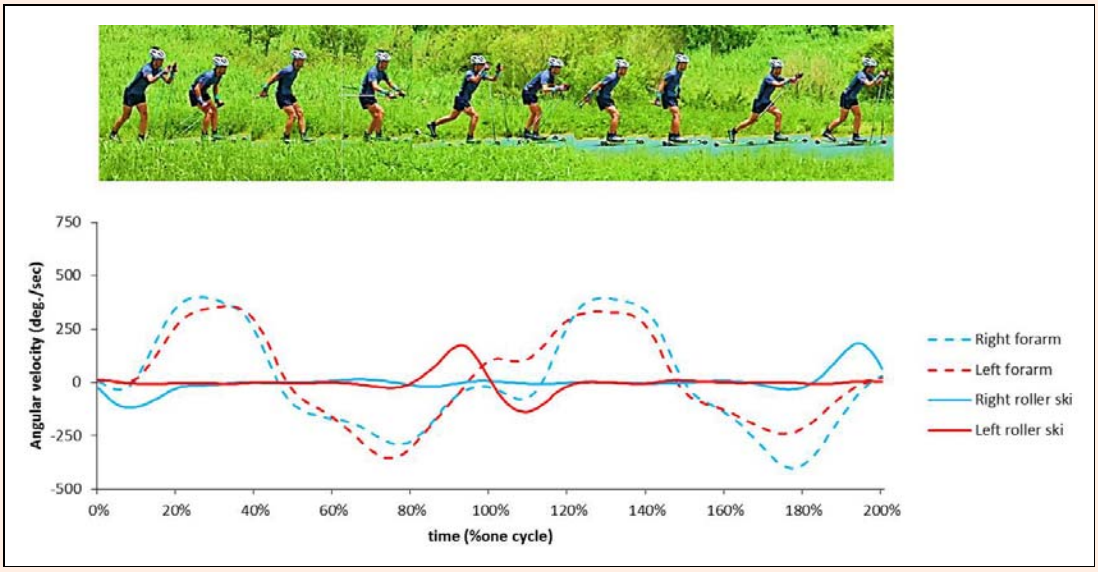


**Figure 3. Angular velocities of forearms and roller skis in the sagittal plane during the kick double-poling technique.**

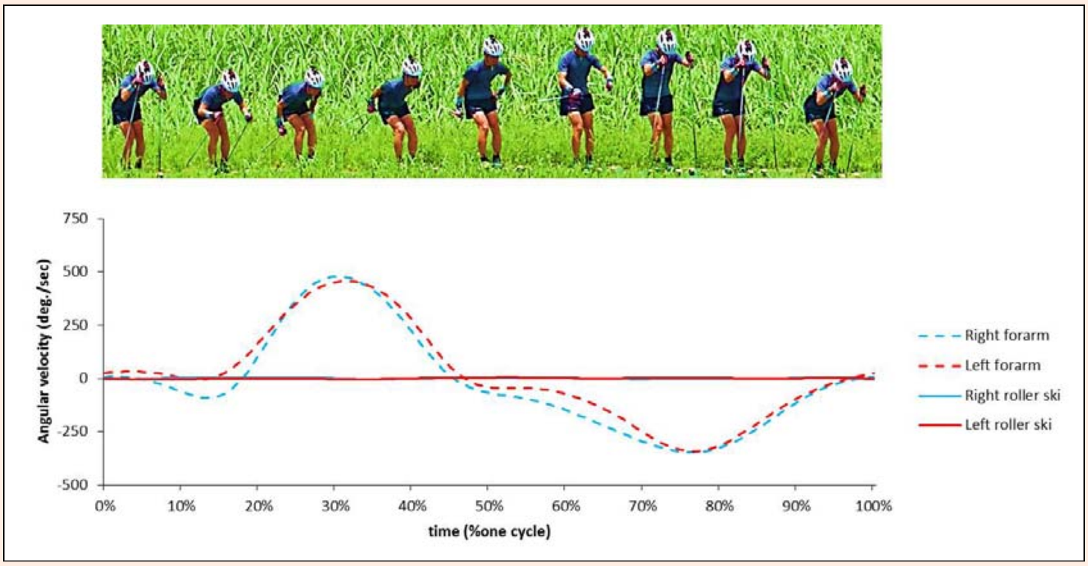


**Figure 4. Angular velocities of forearms and roller skis in the sagittal plane during the double-poling technique.**

attached: two on the wrists and two on the roller skis of the subject. The rollers of the subject and the movements of the pole tips were recorded using a compact digital video camera (Contour+2, Contour Inc., USA). The camera was fixed with a downward inclination to the left side of the helmet and used to collect data for comparison with the automated identification. The skiing velocity of each subject and course situations were measured with a GNSS receiver (SXBlue II GNSS, GENEQ Inc., Canada) and data-receiving PDA (TNJ32, Trimble Navigation Ltd., USA). Selected NMEA messages, GPGGA and GPVTG, were recorded in the PDA at a sampling rate of 5 Hz. Each subject wore a tight-fitting waist bag holding the receiver and PDA. The antenna of GNSS receiver was attached to the top of the helmet. All subjects skied a 6,900-m (3,450 m × 2) roller ski course in the classical-style at their maximum speed.

## Data analysis

Subtechniques were detected using an automatic identification system that was developed based on the results of the pre-experiment. The actual subtechniques used were determined by both the roller skis and the movements of the pole tips observed on the video. This check was carried out visually by one of the author who was a past ski racer and present coach with 17 years of cross-country skiing experience. The total number of cycles and the number of cycles of each subtechnique were calculated by the automatic and visual methods, respectively. The percentages of correct identification by the automatic method were also calculated.

The velocity of the GPVTG data was smoothed by a singular spectrum analysis (Alonso et al., 2005). The coefficients were determined to remove head movement from the raw velocity data. The GNSS data were transferred to 100 Hz using the cubic spline interpolation. The skiers' trajectories and altitudes were calculated by the GPGGA data. The trial time was computed using the reference line corresponding to the start and finish lines.

**Table 2. Number of subtechniques identified by automatic identification and by visual method.**

| | Automatic identification | Vidual check | The number of correct identification |
|---|---|---|---|
| **Total** | 9,661 | 9,444 | 9,307 (98.5%) |
| **DS** | 895 | 910 | 876 (96.2%) |
| **KDP** | 474 | 500 | 428 (84.8%) |
| **DP** | 8,292 | 8,034 | 8,003 (99.6%) |

# Results

## Identification of subtechniques

Table 2 shows the counted number of subtechniques for each method. A total of 9,661 cycles of subtechniques were identified by the automatic identification method. In contrast, a total of 9,444 cycles of subtechniques were identified by the visual method. The total number of cycles correctly identified by automatic identification was 9,307. Some of the incorrect identifications were because of the arm swings during and around the downhill. Twenty and 117 subtechniques were incorrectly detected during the 10 cycles immediately after commencement of

**Table 1. Anthropometric and physical performance characteristics of subjects. Data are means (±SD)(Min-Max).**

| | Men | Women |
|---|---|---|
| **Age (yrs)** | 20.2 (1.5) (18.0-22.0) | 20.6 (1.3) (19.0-22.0) |
| **Height (m)** | 1.75 (.04) (1.72-1.81) | 1.62 (.06) (1.54-1.68) |
| **Weight (kg)** | 71.3 (5.3) (66.5-79.1) | 55.7 (4.5) (48.4-60.8) |
| **$VO_2max$ ($ml·min^{-1}·kg^{-1}$)** | 70.8 (4.0) (65.9-74.9) | 56.8 (4.8) (51.3-64.8) |
| **Heart $Rate_{max}$ (bpm)** | 196 (6) (189-204) | 198 (8) (192-206) |
| **FIS points** | 86.2 (47.4) (39.2-152.9) | 174.4 (71.0) (68.3-NP) |

NP: no points

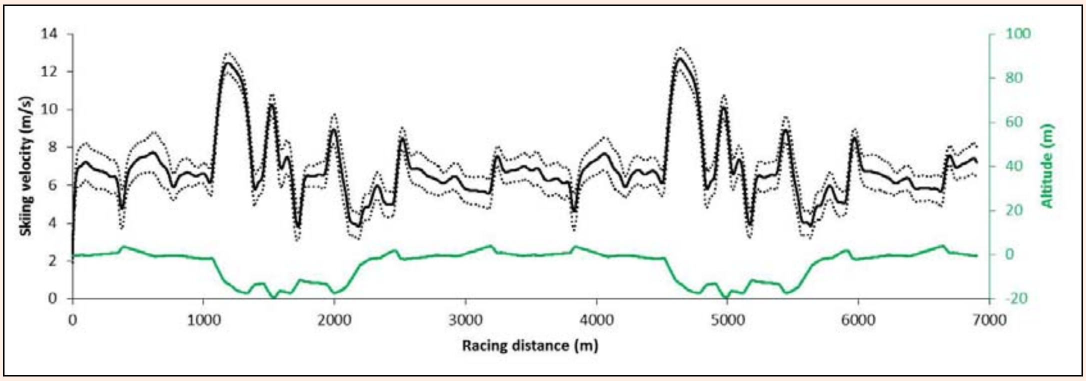


**Figure 5. Skiing velocity (black solid line) and altitude profile (green line) during validation experiment as a function of racing distance (m).**

the measurements and in the transition phases between the subtechniques, respectively. The number of cycles identified by visual method was assumed to be correct and used as the baseline. The percentage of correct identification for each subtechnique is given in Table 2.

### GNSS data

There were 5–18 visible satellites (mean 13.04 ± 1.82) above the site with an elevation mask angle of 5° during the entire measurement. The horizontal dilution of precision (HDOP) values were between 0.7 and 3.4 (mean 0.94 ± 0.20). Before each trial, the satellite availability and HDOP were checked. The trial time was 1,063.8 ± 116.0 s (men: 957.8 ± 18.2 s, women: 1,168.0 ± 46.1 s). The mean velocity was 6.55 ± 0.70 m·s$^{-1}$ (men: 7.20 ± 0.13 m·s$^{-1}$, women: 5.91 ± 0.23 m·s$^{-1}$). Figure 5 shows a time history of the skiing velocity and the course altitude. The skiing velocity changed based on the incline of the course. The maximal speed was occurred at the middle of the steep downhill section in both laps. The distribution of subtechniques as a function of the inclination and skiing velocity is shown in Figure 6 (a) and (b). The markers represent the sampling of one cycle and the data for each gender was superimposed to emphasize the distribution of the subtechniques. The plots with speeds less than 5.0 m/s in the downhill section represent the subtechniques immediately after starting. The highest speed occurred with DP in the -3.0° downhill section. In the uphill section, the male speeds during DP, KDP, and DS were distributed between 4.5 and 10.2 m·s$^{-1}$, 4.0 and 7.3 m·s$^{-1}$, and 3.9 and 5.4 m·s$^{-1}$, respectively (Fig. 6 (a)). Similarly, the female speeds during DP, KDP, and DS were distributed between 3.2 and 9.3 m·s$^{-1}$, 3.2 and 6.0 m·s$^{-1}$, and 2.8 and 4.5 m·s$^{-1}$, respectively (Fig. 6 (b)). The KDP technique was distributed in the same inclination range for both male and female skiers (Figure 6). The female skiers began to use DS at 2.5° uphill (Figure 6 (b)), whereas the male skiers began to use in at a grade of 0.7° (Figure 6 (a)). In addition, the thresholds of DP usage for the female and male skiers were 5.5° and 6.7°, respectively (Figure 6). Above these DP thresholds, the skiers did not use DP. In Figure 6 (b), the identifications corresponding to the three DP plots above 5.5° uphill were incorrect.

## Discussion

The automatic identification method developed in this study was used to correctly identify 9,307 subtechnique cycles out of a total of 9,444 cycles, which indicated an accuracy of 98.5%. The method was thus highly accurate for all the subjects despite their differing cross-country skiing expertise based on FIS points. This result implies that it is possible to identify the subtechniques used by many cross-country skiers using the proposed automatic

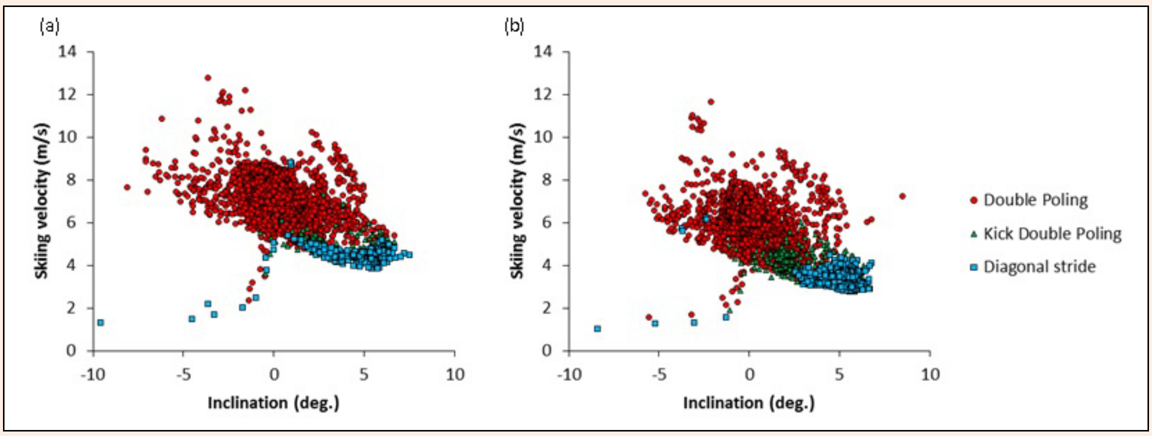


**Figure 6. Subtechnique distribution as a function of inclination and skiing velocity in male (a) and female (b).**

identification method. Moreover, this method can be used during high-intensity training because the sensors are small and light. However, this method did not work well in some conditions: (1) for tracking arm movements during the downhill; (2) for measuring the cycles immediately after the start; and (3) for measuring the transition period between subtechniques. The downhill zones can be distinguished using the position or altitude data of the DGNSS. Thus, the accuracy of identification will be improved by not applying this method during the downhill section. On the other hand, the results in conditions (2) and (3) should be eliminated because the subtechniques in these conditions are not important in evaluating the subtechniques. Further studies are needed for a detailed evaluation of the movement at the beginning and the technique of the subtechnique changes.

In this study, we used an automatic method to identify the subtechniques, and used a small DGNSS module to measure the velocity and course grade. The skiing speed range for DS (3.9–5.4 m·s$^{-1}$ for men and 2.8–4.5 m·s$^{-1}$ for women) was small compared to those for DP (4.5–10.2 m·s$^{-1}$ for men and 3.9–9.3 m·s$^{-1}$ for women) and KDP (2.0–7.3 m·s$^{-1}$ for men and 3.2–6.3 m·s$^{-1}$ for women). In addition, the maximum skiing speeds for DP and DS under simulated race conditions are 12.0 and 6.0 m/s, respectively (Bortlan et al., 2012). However, there is no significant difference between the maximum speeds for DS and those for the other two subtechniques on a flat (Nilsson et al., 2004). This suggests that skiers do not use DS at high-speeds even though they are capable of doing so. The female skiers had three thresholds for subtechnique selection. DP was used below 5.5° uphill and DS was used above 2.5° uphill and below 4.5 m·s$^{-1}$ velocity. This velocity threshold is lower than those of their male counterparts, which are 5.4 and 6.0 m/s according to Bortlan et al. (2012). The patterns of all the female skiers in the subtechnique distribution plot are similar. They all used DP on the flat at high speeds and transitioned to KDP, and subsequently to DS with decreasing skiing velocity and increasing inclination (see Figure 6 (b)). This is in good agreement with observations on a treadmill (Pellegrini et al., 2013). Moreover, this means that female skiers select their subtechniques based on the course grade and skiing velocity. This implies that the distribution of the subtechniques could be useful for analyzing the technical characteristics of skiers.

However, the male skiers had one threshold for subtechnique selection. They used DS below 5.4 m·s$^{-1}$. There was no tendency in their distribution plot regarding course inclination. This was because one male skier did not use DS, and DP constituted 90% of their subtechniques. A certain amount of each subtechnique is required for analysis of the subtechnique transitions based on the course grade. It is also important to clarify the subtechnique distribution on each authorized course from the standpoint of an analysis for the technical characteristics of the skier. As a result, it was found that the distribution of the subtechniques used varied according to the velocity and course grade (Figure 6 (a) and (b)). In general, the distribution of subtechniques reflects the technical characteristics of skiers in each subtechnique. This will clarify the skier's technical level for the various subtechniques and point to a future direction of training to improve the performance in competitions.

## Conclusion

The aims of the present study were (1) to develop an automated identification system using angular rate sensors, and (2) to examine the relationships among the skiing velocity, course conditions, and subtechniques using a DGNSS and an automated identification system. The automated identification method successfully used data obtained by inertial sensor attached to both the forearms of the skier and the roller skis to observe the subtechniques in most situations. Furthermore, we measured the skiing velocity and the course slope by using the DGNSS module. The subtechnique distribution graph was drawn as a function of the inclination and skiing velocity. The distribution would be helpful in showing the technical features of subtechniques of each skier.

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## References

Alonso, F.J., Castillo, J.M. and Pintado, P. (2005) Application of singular spectrum analysis to the smoothing of raw kinematic signals. *Journal of Biomechanics* **38**, 1085-1092.

Andersson, E., Supej, M., Sandbakk, Ø., Sperlich B., Stöggl, T. and Holmberg, H. C. (2010) Analysis of sprint cross-country skiing using a differential global navigation satellite system. *European Journal of Applied Physiology* **110**, 585-595.

Bortolan, L., Pellegrini, B., Impellizzeri, F. and Schena, F. (2012) Automatic detection of technique during on snow cross-country skiing. In: *Science and Skiing V*. Eds: Muller, E., Lindinger, S., Stöggl, T. Meyer & Meyer Sport (UK) Ltd. 483-491.

Hoffman, M.D., Clifford, P.S., Foley, P.J. and Brice, A.G. (1990) Physiological responses to different roller skiing techniques. *Medicine and Science in Sports and Exercise* **22**, 391-396.

Hoffman, M.D., Clifford, P.S., Watts, P.B., Drobish, K.M., Gibbons, T.P., Newbury, V.S., Sulentic, J.E., Mittelstadt, S.W. and O'Hagan, K.P. (1994) Physiological comparison of uphill roller skiing: diagonal stride versus double pole. *Medicine and Science in Sports and Exercise* **26**, 1284-1289.

Li, L. and Caldwell, G.E. (1999) Coefficient of cross correlation and the time domain correspondence. *Journal of Electromyography and Kinesiology* **9**, 385-389.

Marsland, F., Lyons, K., Anson, J., Waddington, G., Macintosh, C. and Chapman, D. (2012) Identification of cross-country skiing movement patterns using micro-sensors. *Sensors (Basel)* **12**, 5047-5066.

Myklebust, H., Nunes, N., Hallén, J. and Gamboa, H. (2011) Morphological analysis of acceleration signals in cross-country skiing – Information extraction and technique changes detection. In: *Proceedings of the International Conference on Bio-inspired Systems and Signal Processing. January 26-29, Rome, Italy*. 510-517.

Myklebust, H., Losnegard, J. and Hallén, J. (2013) Differences in V1 and V2 ski skating techniques described by accelerometers. *Scandinavian Journal of Medicine and Science in Sports*, in press.

Nilsson, J., Tveit, P. and Eikrehagen, O. (2004) Effects of speed on temporal patterns in classical style and freestyle cross-country skiing. *Sports Biomechanics*, **3**, 85-108.

Pellegrini, B., Zoppirolli, C., Bortolan, L., Holmberg, H. C., Zamparo, P. and Schena, F. (2013) Biomechanical and energetic determinants of technique selection in classical cross-country skiing. *Human Movement Science* **32**, 1415-1429.

Sandbakk, Ø., Sandbakk, S.B., Supej, M. and Holmberg, H.C. (2014) The velocity and energy profiles of elite cross-country skiers executing downhill turns with different radii. *International Journal of Sports Physiology and Performance* **9**, 41-47.
Sandbakk, S.B., Supej, M., Sandbakk, Ø. and Holmberg, H.C. (2013) Downhill turn techniques and associated physical characteristics in cross-country skiers. *Scandinavian Journal of Medicine and Science in Sports*, in press.

## Key points

- The automatic identification method, which utilizes data obtained by small and light inertial sensors, could be used to recognize subtechniques of classical-style roller skiing with a high accuracy of 98.5%.
- The skiing velocity was measured using a small DGNSS module at all over the course, which made it possible to evaluate the technical features of skiers together with the results of the automatic identification.
- However, there were limitations in the automatic identification during the start phase, the downhill, and the transition period between subtechniques.

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