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Title: Pole length influence performance during classic style snow-skiing in well-trained cross-country skiers.

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ABSTRACT

Purpose: To investigated how self-selected PLs of ~84% ($PL^{84\%}$) compared to ~90% ($PL^{90\%}$) of body height influenced performance during a 700-m time trial with undulating terrain on snow. **Methods:** Twenty-one cross-country skiers, thereof seven females, performed four trials at a maximal effort in a counter-balanced fashion with $PL^{84\%}$ and $PL^{90\%}$ separated by 20 min breaks between trials. In trials I and II, only DP was allowed (DP_{only}), while during trial III and IV skiers used self-selected classical sub-techniques (CL_{free}). Continuous speed, cyclic parameters and heart rate were collected using micro-sensors in addition to a post time trial rating of perceived exertion (RPE). **Results:** 700-m time with DP_{only} were significantly shorter with $PL^{90\%}$ than $PL^{84\%}$ (mean±CI; -1.6±1.0%). Segment analyses showed higher speed with $PL^{90\%}$ during uphill sections compared to $PL^{84\%}$ (3.7±2.1%), with the greatest difference found for the female skiers (5.6 ± 2.9%). In contrast, on flat terrain at high skiing speeds, speed was reduced with $PL^{90\%}$ compared to $PL^{84\%}$ (-1.5±1.4%); this was only significant for the male skiers. During CL_{free}, pole length did not influence performance in any segments, choice of sub-technique or cycle rate during the trials. No differences in RPE or heart rate between pole lengths were found. **Conclusion:** $PL^{90\%}$ improved performance in uphill's at low speeds when using DP, but hindered performance on flat terrain and at higher speeds compared to self-selected pole lengths. Choice of pole length should, therefore, be made based on race course topography, preferred sub-techniques and the skier's physiological and technical abilities.

Key Words

Cross-country skiing; equipment; GNSS; performance; rating of perceived exertion; skiing technique.

INTRODUCTION

Over the past few decades, cross-country skiing has evolved, with the introduction of new competition forms such as sprint and mass start, changes in the preparation of skis, course profiles, and skiers' equipment and techniques [1,2]. Consequently, with higher average speeds in today's competitions, an increased use of "high speed" sub-techniques in both classical and free style is evident [3,4]. In classical style, the double poling (DP) sub-technique has traditionally been used on flat terrain and at high speeds, whereas the diagonal stride (DS) sub-technique has mainly been used in uphill terrain and at lower speeds [1,5]. However, in recent years DP has been frequently applied in uphill terrain, due to increased speed by the development of upper-body power, endurance and technique in elite skiers [6].

Since propulsive forces during DP are solely generated through the poles, enhancements of pole properties such as pole weight, stiffness and pendulum have emerged [7]. Further, the ways in which pole length affects performance, oxygen cost and kinematics have been thoroughly investigated. Previous studies have shown that increasing pole length from ~84% (normal self-selected length) to ~90% of body height reduces the oxygen costs by lowering the vertical displacement of the center of mass (COM) in DP [5,8-11]. Moreover, as DP in different terrains and speeds demands different movement patterns to overcome external forces [7,8], the effects of the beneficial effect of longer poles seems to increase in uphill terrain, and consequently, reduced in flat terrain [8]. However, except for a study by Hansen, Losnegard [5], the influence of pole lengths has only been investigated during treadmill roller-skiing. Hence, investigating the influence of pole lengths on performance in undulating terrain outdoors seems warranted [9]. Moreover, no data are available on female skiers, and the effect of pole lengths on performance in other classic style sub-techniques such as DS has not so far been investigated.

An evidenced-based approach to assess the influence of pole length on performance is also important from a rules and regulations perspective. Recently, the International Ski Federation (FIS) introduced a pole length rule (valid from the 2016/17 season) stating that athletes are not allowed to use poles longer than 83% of their body height, including ski boots (~85% without boots) during classical races. However, scientific evidence on the effects of pole length in "real-life competitions" is limited. Moreover, from a practical point of view, changes in equipment in cross-country skiing has traditionally been evaluated by heart rate (HR) or rating of perceived exertion (RPE). Based on lab experiments, such methodology may have several disadvantages to detect small performance changes and information about its validity in field conditions is therefore warranted [8,9].

The aim of the present study was to compare skiing performance with pole lengths of ~84% and ~90% of body height in a 700 m (~2 min) time trial on snow, using the classic style techniques. The course consisted of downhill, uphill and flat terrain. By differentiating the course into segments, we were able to evaluate the influence of pole length on skiing performance in different terrains. Moreover, we aimed to test the effect of pole length in DP only (DP_{only}) and free choice of classical sub-technique (CL_{free}) during the time trial. We hypothesized that longer poles would improve performance in uphill terrain when using the DP technique, and that the difference between pole lengths would be smaller or non-existent in flat terrain and at high speeds. Moreover, HR and RPE would not be valid tools for investigating difference in performance when changing equipment in cross-country skiing.

METHODS

Subjects

Seven female (age 19 ± 3 yrs, body height 168 ± 5 cm, body mass 64 ± 4 kg, self-selected pole length classical 84.1 ± 0.5 %) and 14 male (age 21 ± 4 years, body height 180 ± 7 cm, body mass 70 ± 9 kg, self-selected pole length classical 84.3 ± 0.5 %) skiers were recruited to the project. Their maximal aerobic power during running (females; 59.8 ± 2.0 $ml \cdot kg^{-1} \cdot min^{-1}$, males; 73.5 ± 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$) was determined on a separate day ± 2 months from the test day (for protocol see [12]). All skiers were highly trained regional-level junior and senior athletes, ranking in the top 30 at the national Norwegian Cup. The study was conducted according to the Declaration of Helsinki and Norwegian law. All subjects gave their written informed consent before participating in the study.

Design

The skiers performed four trials on a cross-county skiing course in Holmenkollen (Oslo, Norway); two with self-selected pole lengths (~84% of body height; $PL^{84\%}$) and two with long poles (90.1 ± 0.6 and 90.4 ± 0.9 %, female and male respectively; ~90% of body height; $PL^{90\%}$). In the two first trials skiers used DP_{only}, while in trials three and four the skiers used CL_{free}. The order of pole lengths in the DP_{only} and CL_{free} conditions was counterbalanced. The course was 700 m and separated into seven segments based on different types of terrain **(Figure 1 and 4C)**. During the race, the skiers wore an integrated IMU and GNSS unit on their backs (between thoracic vertebrae 4 and 5), to capture continuous speed and sub-technique parameters. Split-times for each segment were determined by placing custom-made timing gates at the start and end of each segment. Heart rate and RPE were monitored during the tests.

[Figure 1-2 near here]

Methodology

700 m on-snow trial

Prior to the trials, the skiers performed a warm-up consisting of 20 min of low-intensity skiing, including three short periods (20-30 sec) with increasing speed. Before the start of every trial a test of glide friction was performed [16]. The test was conducted using 4 photocells a fixed distance along a downhill slope (~8°), which the skiers skied through in a standing position. Thereafter, the skiers performed the trial (~700 m x 4, break: ~20 min). Subjects were instructed to perform all trials with maximal effort and to stay in the classic track throughout the entire course, including all turns. During the breaks, the skiers were allowed to ski at low intensity using a different pair of skis. Due to the snow conditions, only 3 females and 7 males did the CL_{free} in the two last trials (n=10). The remaining eleven skiers did DP_{only} also for the two last trials, resulting in a total of 32 tests for DP_{only}. Immediately after each trial the skiers were asked to rate their perceived exertion (RPE; 6-20) [13], and after trials 2 and 4 they were asked to compare the performance (speed) of the two pole lengths during the "Slightly downhills", " Uphill", "Flat" and "Total" based on a customized Likert comparison scale **(Table 1)**.

[Table 1 near here]

Apparatus

All skiers used their own skis, boots and poles. All subjects used the same type of poles for both pole lengths. All skis were prepared identically (Swix CH6, Lillehammer, Norway) by a professional ski-waxer, and the classic skis were prepared with the most suitable kick-wax for the respective conditions. A differential GNSS (dGNSS) with a local base station and a rover (antenna rover: G5Ant-2AT1 (Antcom, Torrance, CA, USA), antenna base: GrAnt - G3T (Javad GNSS, San José, CA, USA), receiver: Alpha-G3T (Javad GNSS, San José, CA, USA)) was used to accurately [14] capture the skiing track and course segments (length and height) in

3D. Speed and movement data were collected with an integrated IMU and GNSS unit (Optimeye S5, Catapult Innovations, Melbourne, Australia), validated by Gløersen, Kocbach, Gilgien [15]. The unit consisted of a 10Hz GNSS-receiver, tracking both GPS and GLONASS data, a 3D accelerometer (100Hz), a 3D magnetometer (100Hz) and a 3D, 2000 deg·sec^{-1} gyroscope (100Hz). The custom-made timing gates consisted of a spring-loaded horizontal bar placed ~30 cm above the snow surface which was attached to a vertical anchor. A GNSS-IMU unit was attached to the bar **(Figure 2)**. When a skier passed and released the gate, it was registered in the IMU attached to the bar. The IMU signal was used to determine the intermediate times as the skiers passed the bar. Polar Team2 (Polar Electro Inc, Lake Success, NY, USA) heart rate sensors, compatible with the Optimeye S5 units, were used to register HR. Speedtrap II TC Wireless timing system photocells (Brower Timing Systems, Draper, Utah, USA) were used for the friction test. VO_{2max} during running was measured on a treadmill (Woodway ELG, GmbG, Weil am Rein, Germany) oxygen consumption was measured using an automatic ergo-spirometry system (Oxycon Pro, Jaeger Instrument, Hoechberg, Germany). The subjects started at 8 km·t^{-1} (female) or 9 km·t^{-1} (male) at 10,5 % incline. Thereafter, the speed was increased by 1 km·t^{-1} until exhaustion. Oxygen uptake and heart rate was measured continuously, and the highest mean values over 1 minute was taken as VO_{2max} and maximum heart rate (HR_{max}), respectively.

Data analyses

Segment times and total 700 m times were determined from the timing gate accelerometer-data, using custom-made software in LabView (National Instruments, Austin, TX, USA). Data from the IMU-GNSS sensors carried by the athletes were used to detect the speed and movement patterns of each athlete within the segments. Speed was calculated from changes in GNSS position data per time unit, while cycle frequency and technique subtype were detected from the IMU. The criteria to detect cycle frequency and sub-technique subtype were adjusted for each skier individually to allow the software to detect these sub-technique characteristics automatically. To detect these parameters rotational jerk was calculated from the IMU recordings of the skiers back and forth movements in the sagittal plan, derived from the forward movement magnetometer data. Only segment 1, 3, 5 and 7 were analyzed for sub-technique (cycle frequency and technique subtype) due to problems with clear classifications of sub-techniques in the two downhill segments (2 and 6) and the 90 degree turn in segment 4.

To obtain an accurate course profile a carrier phase differential position solution was processed on the dGNSS data using the geodetic post – processing software Justin (Javad GNSS, San José, USA) (Gilgien et al., 2014) for each test day specifically as grooming caused some variability in segment length between days. In the ski friction test, timing data from the four friction tests were used to calculate alterations in speed, and together with the track slope, the coefficient of friction was calculated [16]. The friction (μ) was similar for both conditions (0.014 ± 0.005 during DP_{only} and 0.013±0.007 during CL_{free}) and was not significantly different between trial 1 and trial 2, nor between trial 3 and trial 4.

Statistical Analysis

Data are presented as mean ± standard deviation (SD), for relative differences between pole lengths means ± 95% confidence intervals (CI) [17], and for RPE median ± inter quartile range (IQR) is used. The effects of pole length on segment- and total times were analyzed using two-factor within-subject repeated measures ANOVA (8 x 2 design), with all subjects included and with females and males considered separately. Including both gender subjective impression of achieved performance between poles within the sub-techniques were analyzed with one-way repeated measures ANOVA for the segments “slightly downhill”, “uphill” and “flat”, while paired student t-test was calculated for the "total". For ANOVA calculations, Bonferroni post-hoc tests were used to determine whether differences were statistically significant. Subjective RPE (Borg) between pole lengths was analyzed with Wilcoxon matched-pairs signed rank test. Paired sample t-tests were used to calculate the differences in sub-technique and subjective measurements between the pole lengths. A P-value $\leq$ 0.05 was considered statistically significant and P-values $\leq$ 0.10 were considered tendencies. Statistical analyses were performed using Microsoft Office Excel 2013 (Microsoft, Redmond, WA, USA) and IBM SPSS Statistics 21.0 (International Business Machines, Armonk, NY, USA). All figures were created using MATLAB (R2016a, The MathWorks, Inc, Kista, Sweden).

RESULTS

700 m time

The 700 m time with DP_{only} was significantly shorter with $PL^{90\%}$ than $PL^{84\%}$ when including both female and male skiers (n = 32) (mean ± CI; -1.6 ± 1.0 %, *P* = 0.003) **(Figure 3A)**. Separating sexes, the female skiers showed a reduced 700 m time with $PL^{90\%}$ compared to $PL^{84\%}$ (-2.9 ± 2.2 %, *P* = 0.014), while a tendency to difference were found among the males (-1.0 ± 1.1 %, *P* = 0.08) **(Figure 3B and C)**. The 700 m time with CL_{free} (n = 10) was not significantly different between $PL^{84\%}$ and $PL^{90\%}$ (-0.1 ± 1.2 %, *P* = 0.80) **(Figure 3D)**.

700 m segment time

With DP_{only} (n = 32) including both sexes, $PL^{90\%}$ produced a significantly reduced time compared to $PL^{84\%}$ in segments 3 (-3.7 ± 2.1 %, *P* = 0.001), 4 (-3.3 ± 1.8 %, *P* = 0.001), 5 (-1.5 ± 1.4 %, *P* = 0.037) and 7 (-2.1 ± 1.7 %, *P* = 0.014) **(Figure 3 and 4A)**. Separating sexes, the female skiers reduced their times with $PL^{90\%}$ compared to $PL^{84\%}$ in segments 3 (-5.6 ± 2.9 %, P = 0.002), 4 (-5.1 ± 2.8 %, P = 0.002), and 5 (-2.5 ± 2.0 %, P = 0.02), in addition a tendency to difference were found in segment 7 (-4.0 ± 4.3 %, P = 0.06). The males reduced their times with $PL^{90\%}$ compared to $PL^{84\%}$ in segment 4 (-2.4 ± 2.3 %, P = 0.04), and a tendency was found in segment 3 (-2.7 ± 2.9 %, P = 0.07). In contrast, the male skiers increased their times with $PL^{90\%}$ compared to $PL^{84\%}$ in segment 6 (1.5 ± 1.4 %, P = 0.03). For CL_{free} (n=10), no difference was found in segment times between pole lengths **(Figure 3D)**.

[Figure 3-4 near here]

Distribution of sub-techniques

During CL_{free} in segment 1, 3, 5 and 7, only DP and DS were used by the athletes. Pole length had no significant influence on choice of sub-technique during the trials (P > 0.05) **(Table 2)**. Nor were there any significant differences in cycle frequency between the pole lengths for either CL_{free} or DP_{only} (P > 0.05).

[Figure 5, Table 2 and Table 3 near here]

Subjective measurements and heart rate

RPE did not differ between pole lengths in any of the trials (DP_{only}: P = 0.2, CL_{free}: P > 0.99) (Table 3). Based on the scale in Table 1, $PL^{90\%}$ was rated significantly faster (P = 0.02) in slightly downhill terrain than $PL^{84\%}$ during DP_{only} while $PL^{84\%}$ was rated significantly faster than $PL^{90\%}$ in uphill terrain during CL_{free} (P = 0.01) (Figure 5). For HR there were no differences between pole lengths during neither DP_{only} nor CL_{free} (Figure 4B).

DISCUSSION

The main findings in the present study were: (I) $PL^{90\%}$ improved performance compared to $PL^{84\%}$ during DP_{only} in a 700 m course consisting of undulating terrain. However, when the sexes were separated, the difference between pole lengths was only evident for females. (II) With DP_{only}, the females were faster with $PL^{90\%}$ compared to $PL^{84\%}$ in the uphill segments, while the males reduced their segment time with $PL^{84\%}$ compared to $PL^{90\%}$ in flat terrain. (III) With CL_{free}, the pole length did not influence performance or the preferred use of the sub-techniques (DP or DS) in different terrains. (IV) RPE and HR is not valid tools for determining difference in performance between pole lengths.

Since the early 1990s the effect of pole length in DP has been thoroughly investigated in terms of the effect on O_2-cost [9,11,18,19] as well as performance [5,9]. However, except for the investigation by Hansen and Losnegard [5], all previous studies have used indoor treadmill testing. Such methodology is appropriate for understanding the mechanisms behind changing pole lengths, but lacks ecological validity. Thus, the present study adds knowledge about how pole lengths influence performance in various terrains and at different speeds on snow, using different classic sub-techniques. The present study supports previous findings from treadmill testing, which indicated that longer than self-selected pole lengths increase performance on moderate to steep uphill terrain, but not on flat terrain [8]. In studies that have observed improved performance or reduced O_2-cost with longer pole lengths, the speed on the treadmill has been relatively low with inclined gradients (1- 4.5°, $\leq$ 5.2 $m\cdot s^{-1}$) [9,11]. However, the varying speeds in our study (~3 to ~11 $m\cdot s^{-1}$) more closely resembled a real-life competition [20], which increases the practical applications for coaches and athletes seeking to enhance DP performance.

In the present study, both male and female skiers were investigated, which to our knowledge has rarely been done previously. For the male skiers, there were no significant differences between pole lengths for the overall 700 m time. Interestingly, in segment 6, with the highest achieved speeds, a significantly higher speed was reached using $PL^{84\%}$ compared with $PL^{90\%}$. In contrast, the female skiers showed a significant increase in performance with $PL^{90\%}$ compared to $PL^{84\%}$ in the uphill segments, where the lowest speeds were achieved. This is somewhat in contrast to the findings of Hansen and Losnegard [5], who found that poles 7.5 cm longer than normal length (84% of body height) were ~1% faster than normal poles during an 80 m flat sprint on snow. However, a closer analysis of the results obtained by Hansen, Losnegard [5] indicates that the advantages of the longer poles were mainly achieved in the acceleration phase (0-40 m), when the speed was low (0 to ~6.5 $m \cdot s^{-1}$). This is also supported by Nilsson et al. [10] who reported that using normal +7.5 cm poles resulted in a longer poling time with higher anteroposterior reaction forces when DP at 3.92 $m \cdot s^{-1}$. Taken together, longer pole lengths seem to be advantageous during the acceleration phase and during low speeds (<5 m/s), whereas shorter poles are beneficial in flat terrain at high speeds. This may be related to the fact that DP in different terrains and speeds demands different movement patterns to overcome external forces. In uphill segments, repositioning time is one of the main limiting factors during DP [7]. Since longer poles lead to a higher COM position and less displacement of the COM within each cycle, the reposition distance is therefore shorter with longer poles. Moreover, during the poling phase the distance between poles and COM is smaller with longer poles, resulting in a smaller external moment arm and torque in the working joints [8]. These aspects seem beneficial in uphill DP, by increased cycle length since cycle frequency was similar between pole lengths. However, at high speeds, producing force over a short contact time (20-30 ms) is a specific demand of flat DP skiing. Here, skiers must potentially increase their distance between COM and poles to gain sufficient time for "pre-activation" before peak pole force occurs. Moreover, with shorter pole lengths, the pole tip is placed further forward relative to the COM in $PL^{84\%}$ than $PL^{90\%}$, which seems to be a favorable strategy at high speeds [1,21]. In addition, air drag constitutes a substantial difference between indoor treadmill testing and outdoor testing, which should be taken into consideration when interpreting the results from different studies. At increasing speed outdoors, combined with an increased frontal area with longer poles [8], the air drag on skiers increases in a quadratic fashion, which implies that a substantial fraction of the increase in propulsive power is dissipated to overcome the increase in air drag resistance. [22]. Taken together, these findings may help to explain how pole length influences performance in various terrains and at different speeds.

To our knowledge, this is the first study to investigate the differences between pole lengths using different skiing sub-techniques. The results from CL_{free} showed that the pole length did not affect performance, cycle frequency or the use of preferred sub-techniques (DP or DS). Interestingly, the skiers rated the $PL^{84\%}$ faster than the $PL^{90\%}$ in uphill segments when using DS. As stated by Losnegard, Myklebust, Skattebo, Stadheim, Sandbakk, Hallen [9], arm movement (“low shoulder”) in the repositioning phase is of great importance to allow for effective propulsion by the legs during DS. This "low shoulder" might be more difficult to achieve with longer pole lengths, and thus influence the skiers’ ratings. In addition, the skiers rated $PL^{90\%}$ faster in slightly downhill terrain and at high speeds, which is in contradiction to their actual performance. Moreover, the choice of equipment among cross-country skiers is often based on subjective rating or from HR analyses. However, the present study adds to previous studies on pole length that this could not detect differences between pole lengths [5,8,9], which imply that performance tests are necessary to understand how the equipment in general interacts with performance.

Methodical considerations

Conducting experiments in the field with high-level athletes requires valid methods suitable for investigating small differences in performance. Using dGNSS allowed tracking of athletes as a point mass model for position, speed and acceleration [3,23,24] with good accuracy, as previously demonstrated during cross-country skiing [3,23,25,26,27]. Marsland et al. [28,29] concluded that the Catapult S5 used in this study can detect race strategy and different sub-techniques in the classic skiing style by making use of the IMU data. In recent studies the accuracy of standalone GNSS-based athlete tracking was improved with the use of a reference trajectory of the track captured by a dGNSS, which could detect typical speed differences in cross-country skiing [15] and the correct order of magnitude in power and external force [30]. The present study extended the use of IMU–GNSS units for timing by mounting them to a timing gate to measure split times.

PRACTICAL APPLICATION

The present study implies that choice of pole length depends on the speed, which potentially is decided by level, sex and the course profile. Hence, to optimize performance in DP, skiers should use longer pole lengths in courses were uphill segments are the most important for overall performance, whereas pole lengths of ~84% of body height should be used if high speeds are decisive in the final results. The present results may stimulate new ideas for developing poles that could be adjusted in length during skiing to optimize performance at varying speeds and in diverse terrain. However, it should be noted that the current rule does not allow pole lengths of more than 83% of skiers’ body height (including ski boots) during FIS races. FIS has also included "zones" during uphill segments, where skiers are restricted to using DS only. Based on the present study we question the rationale for the pole length rule when no difference in time was found between pole lengths when DS was used. Finally, when evaluating equipment in cross-country skiing, a performance test should be used as RPE or HR does not seem to be a valid tool to determine small performance differences in cross-country skiing.

CONCLUSIONS

Double poling performance during a 700 m time trial on snow with undulating terrain increased with pole lengths of 90% compared to 84% for female but not for male skiers. Segment analyses showed that females improved their DP performance using $PL^{90\%}$ compared to $PL^{84\%}$ in uphill terrain, while DP with $PL^{84\%}$ was favorable on flat terrain for male skiers. Pole lengths did not influence performance and choice of sub-techniques when all classic sub-techniques were allowed. Finally, we conclude that the rating of perceived exertion and heart rate are not valid tools for investigating the effect of pole lengths in cross-country skiing.

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FIGURE CAPTIONS

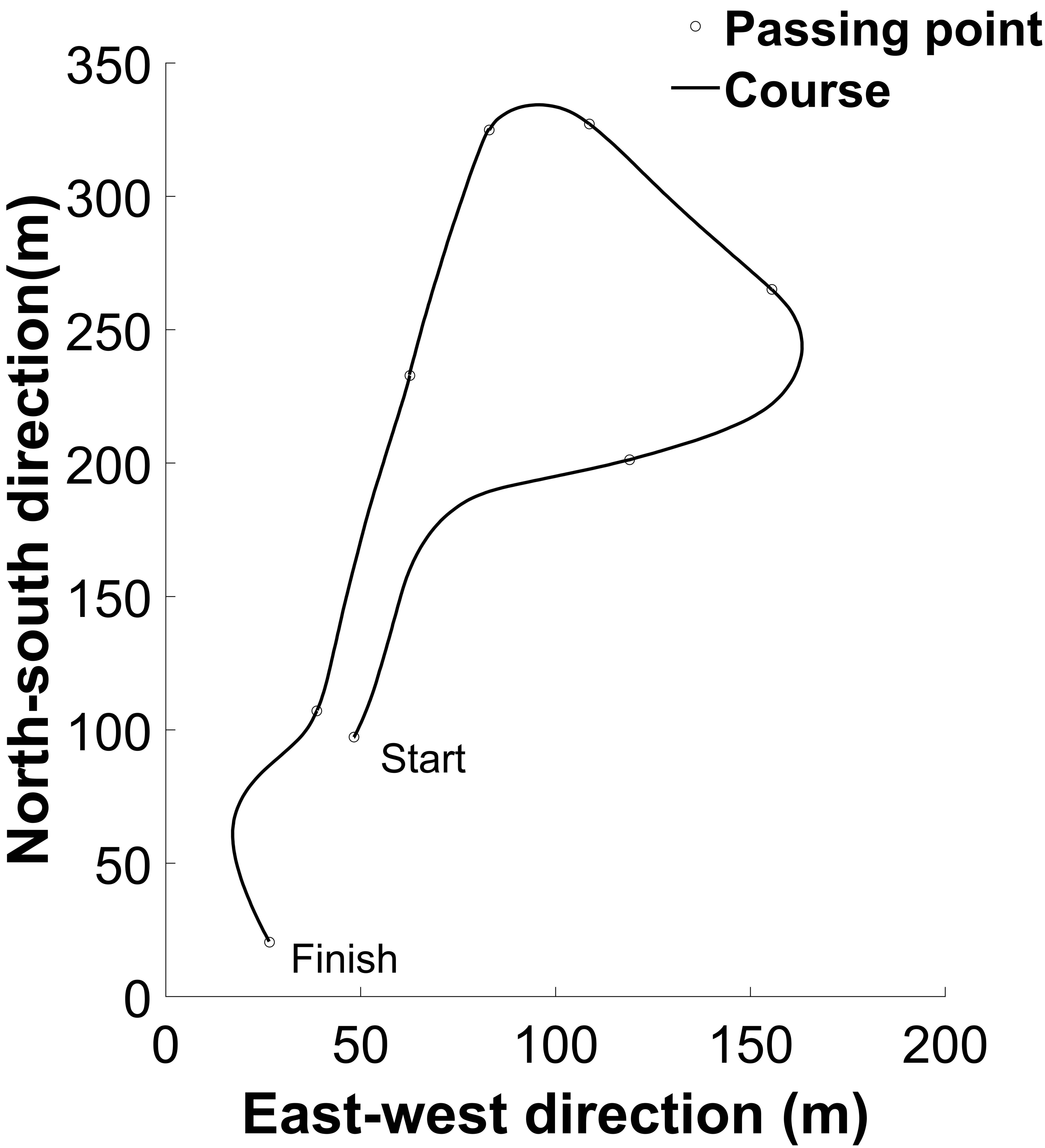
Figure 1: Course map drawn from the dGNSS-data including the segment divisions.

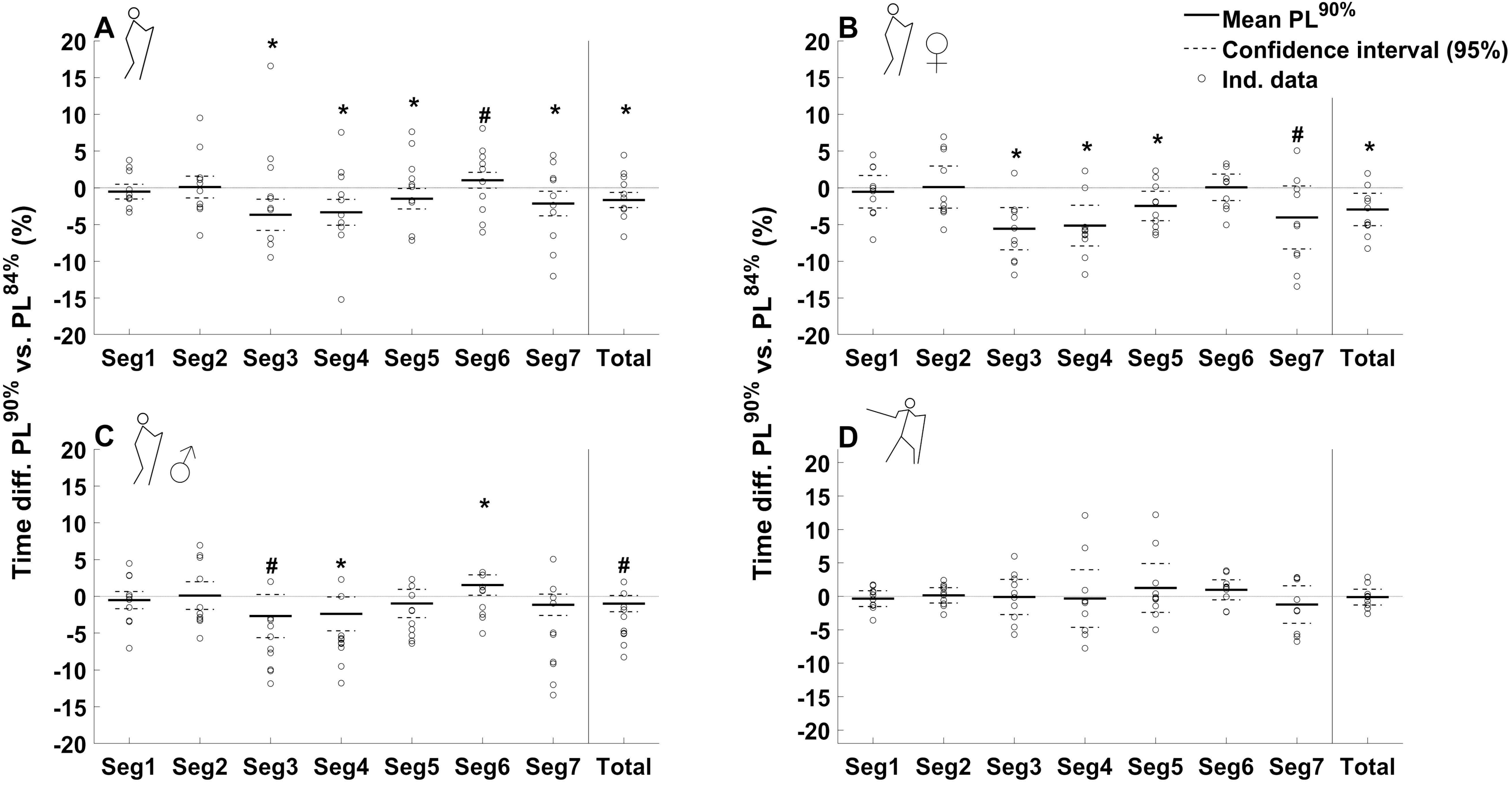
Figure 2: Custom-made timing gate with the microsensor (red circle) placed over the track. When the subject hits the horizontal bar, a timestamp is registered by the microsensor.

Figure 3: Difference in time (%) for the specific segments and total time difference between pole lengths of 90% and 84% of body height. In Figures A-C skiers used DP only (DP_{only}), whereas in Figure D skiers could use self-selected classic sub-techniques (CL_{free}). (A) $PL^{90\%}$ compared with $PL^{84\%}$ DP_{only} including both sexes (n=32). (B) $PL^{90\%}$ compared with $PL^{84\%}$ DP_{lonly} for females (n=11). (C) $PL^{90\%}$ compared with $PL^{84\%}$ DP_{only} for males (n=21). (D) $PL^{90\%}$ CL_{free} compared with $PL^{84\%}$ CL_{free} (n=10). * significant differences between $PL^{90\%}$ and $PL^{84\%}$ ($P \leq 0.05$). # tendencies between $PL^{90\%}$ and $PL^{84\%}$ ($P \leq 0.10$). Solid horizontal line is mean; short dotted line is the confidence interval.

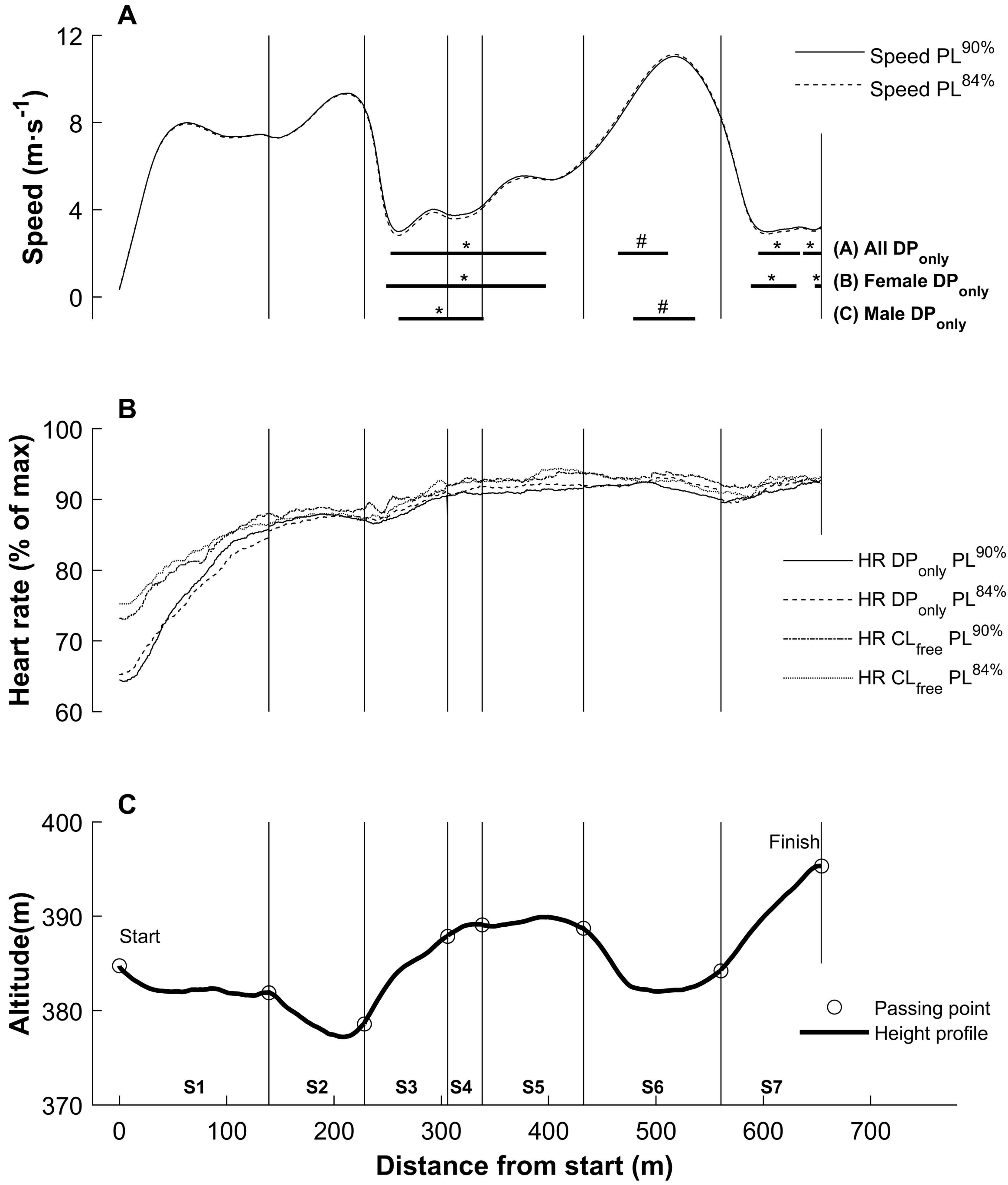
Figure 4: (A) Mean speed curve ($m \cdot s^{-1}$) during the 700 m time trial for $PL^{90\%}$ and $PL^{84\%}$ DP (n=32). Vertical bars indicate significant areas between $PL^{90\%}$ and $PL^{84\%}$ for all (A) (n=32), (B) female (n=11) and (C) male (n=21). * : $PL^{90\%}$ significantly faster than $PL^{84\%}$ ($P \leq 0.05$). # : $PL^{84\%}$ significantly faster than $PL^{90\%}$ ($P \leq 0.05$). (B) Relative heart rate for $PL^{90\%}$ and $PL^{84\%}$ during double poling only (DP_{only}) (n=32) and with use of self-selected classic sub-techniques (CL_{free}) (n= 10). (C) Course profile drawn from the dGNSS-data. All figures also show the segment divisions.

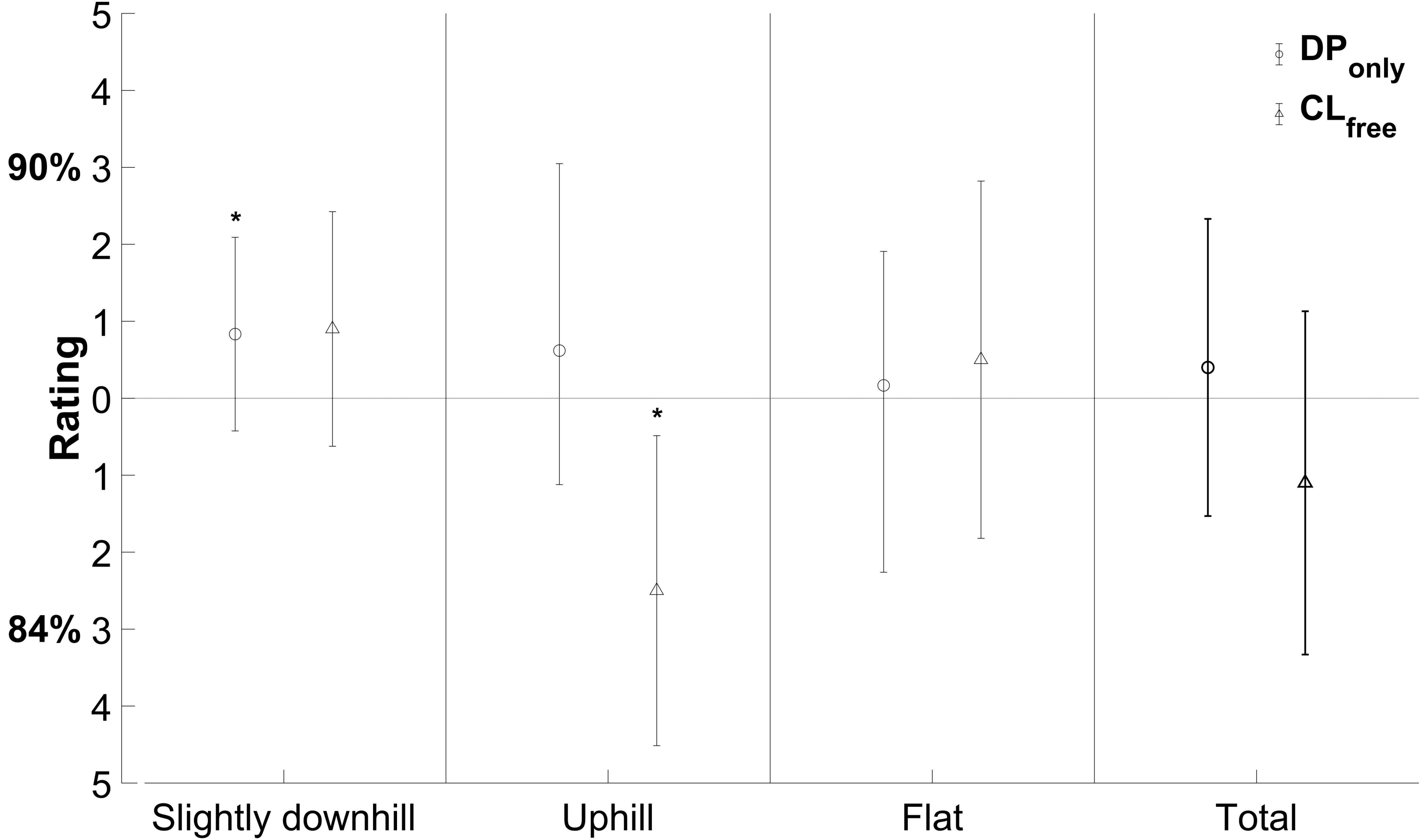
Figure 5: Subjective speed comparison in different terrains and total based on table 1. Over zero-line means $PL^{90\%}$ felt fastest, below zero-line means $PL^{84\%}$ felt fastest. Data presented as mean ± SD. *: Subjective rating significantly different from zero ($P \leq 0.05$).


Passing point
Course
North-south direction(m)
East-west direction (m)
Start
Finish
0
50
100
150
200
250
300
350
0
50
100
150
200



A
B
C
D
Mean $PL^{90\%}$
Confidence interval (95%)
Ind. data
Time diff. $PL^{90\%}$ vs. $PL^{84\%}$ (%)
Seg1
Seg2
Seg3
Seg4
Seg5
Seg6
Seg7
Total


A
Speed (m·s-1)
Speed PL90%
Speed PL84%
(A) All DPonly
(B) Female DPonly
(C) Male DPonly
B
Heart rate (% of max)
HR DPonly PL90%
HR DPonly PL84%
HR CLfree PL90%
HR CLfree PL84%
C
Altitude(m)
Start
Finish
Passing point
Height profile
S1
S2
S3
S4
S5
S6
S7
Distance from start (m)



DP only
CL free
90%
84%
Rating
5
4
3
2
1
0
1
2
3
4
5
*
*
Slightly downhill
Uphill
Flat
Total

Table 1: Scale for subjective rating of performance comparison between pole lengths. Rating "0" indicate same performance (speed) and up or down means increased performance with $PL^{90\%}$ and $PL^{84\%}$, respectively. Rating "5" is substantially faster and 2 is slightly faster etc., illustrated by the coloring.

Rating	Feeling
5	*$PL^{90\%}$ fastest*
4	
3	
2	
1	
0	*Same speed*
1	
2	
3	
4	
5	*$PL^{84\%}$ fastest*

Table 2: Percent sub-technique distribution (mean ± SD) in segments 1, 3, 5, and 7 with different pole lengths during CL_{free}. Only double poling (DP) and diagonal stride (DS) were used. Data are mean ± SD.

	$DP^{PL90\%}$	$DP^{PL84\%}$	$DS^{PL90\%}$	$DS^{PL84\%}$
Segment 1	94 ± 4	96 ± 6	6 ± 4	4 ± 6
Segment 3	10 ± 14	9 ± 14	90 ± 14	91 ± 14
Segment 5	100 ± 0	100 ± 0	0 ± 0	0 ± 0
Segment 7	5 ± 3	5 ± 3	95 ± 3	95 ± 3

Table 3: RPE given by the subjects directly after the DP_{only} and CL_{free} time trials, with use of PL90% and PL84%, respectively. Data is given as median ± IQR.

	DP_{only}	CL_{free}
$PL^{90\%}$	17 ± 2	16 ± 3
$PL^{84\%}$	17 ± 1	16 ± 4