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Choice of sub-technique in classical cross-country skiing

The influence of power and external load on choice of technique in classical roller-skiing

Master's thesis in Physical Activity and Health - Movement Science
Supervisor: Gertjan Ettema
Co-supervisor: Knut Skovereng and Jørgen Danielsen
May 2021

Master's thesis

NTNU
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Department of Neuromedicine and Movement Science

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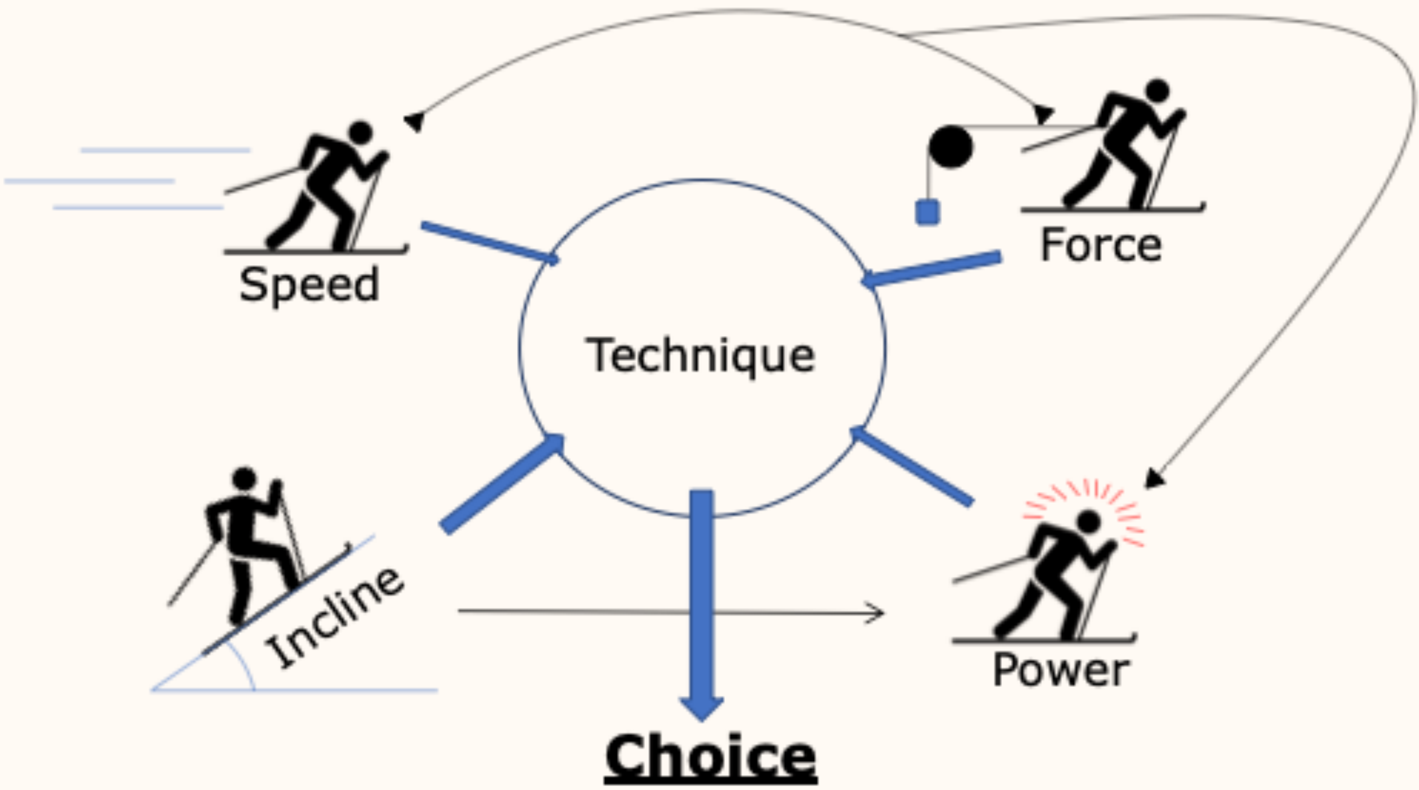
Which factor determine choice of technique?

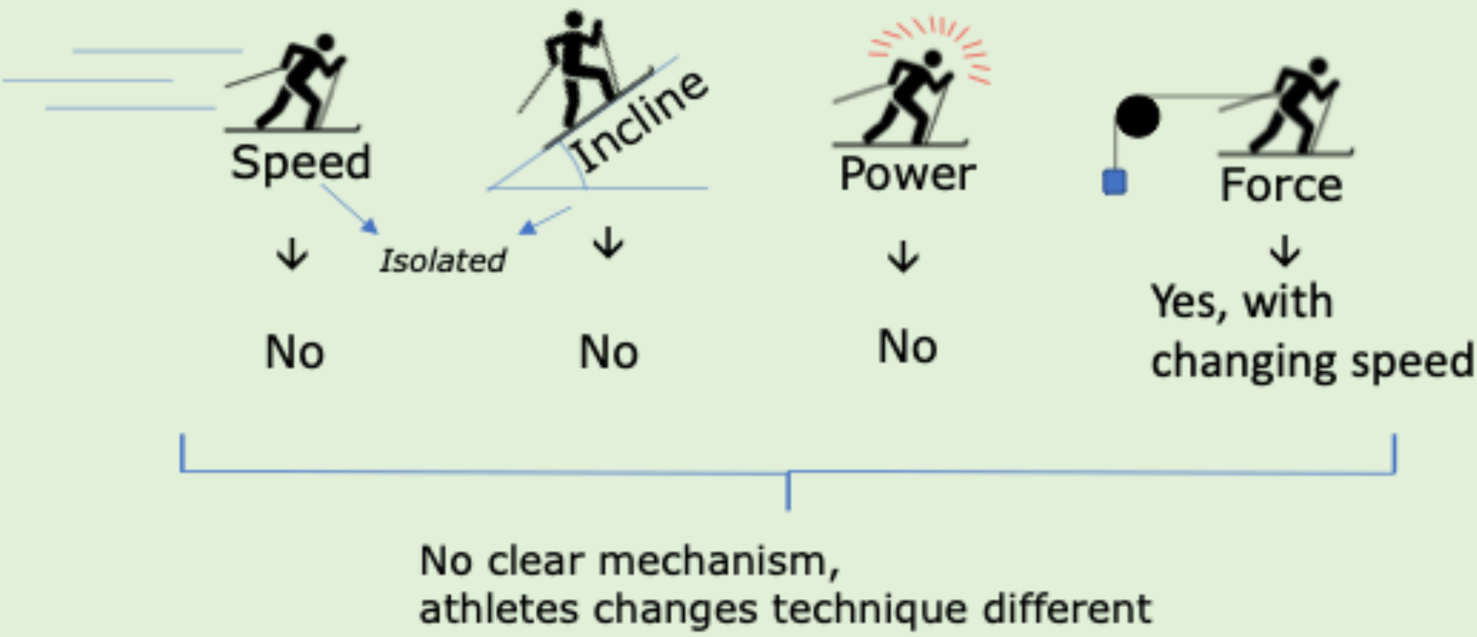
From diagonal stride, double polling with kick, and double polling

Lab → Controlled conditions

Two different speeds and inclines → With polley weight we can manipulate power without changing speed or incline

Is it incline, speed, or load?





Abstract

Purpose: In cross-country skiing the classical style there are three main techniques are diagonal stride (DS), double poling (DP) and double poling with kick (DK). In classical style, in training and competition, different sub-techniques are used mostly depending on terrain. The purpose of this study is to investigate if external workload will have impact on the spontaneous change in technique in classical cross-country skiing. Workload was regulated by changing a resistance force.
Methods: Six males (age 24.1 ± 2.1, body weight 77.6 ± 4.4 and height 180.5 ± 1.7) and eight females (age 21.7 ± 1.7, body weight 62.6 ±7.1 and height 169.7 ± 3.6). The athletes performed four different tests. Each test lasted maximally 6 min and 20 sec. Each condition consisted with an incremental initial and reversed order of external load. With using external load, speed, and incline we were able to isolate one of the parameters. At the start of each test, an offset external load of 500g. From this onset load, 500g was added every 20th second, up to a maximal of 5 kg at 3 min.
Results: There was an overlap in power of the different sub-techniques that show that the minimum power of use in DS was significantly lower than maximum DK, and maximum DP and minimum ($p<.001$). There was a statistically significant interaction effect between incline and choice of technique ($p<.001$), but not significant between speed and choice of technique ($p=.521$). There was a significant effect of hysteresis in transition between up and down protocol in technique shift DP to DK in condition 10 km/h and 8% incline ($p=.012$) and at 12 km/h and 8% incline ($p=.004$), and for condition for DK to DS, 10 km/h and 5% incline ($p=.025$).
Conclusion: Power plays a role in technique use but does not seem to act as a control parameter. In some conditions, the resistance force seems to act as a control parameter, at least for the DK-DP transition. Speed did not affect the force of transition; the amount of external load was the same at which the athletes switched from DK to DP. The overall outcome indicates that incline is a stronger determinant for choice of technique than speed.

Sammendrag

Formål: I klassisk stil i langrenn er det tre hovedteknikker som er diagonal gang (DG), staking (ST) og staking med fraspark (STF). I klassisk stil, brukes ulike delteknikker mest avhengig av terreng. Hensikten med denne studien er å undersøke om ytre belastning vil ha innvirkning på den spontane endringen i teknikken i klassisk langrenn. Den ytre belastingen ble regulert ved å endre en motstandskraft.
Metoder: 6 menn (24,1± 2,1, kroppsvekt 77,6± 4,4 og høyde 180,5 ± 1,6 ± 4,4 og høyde 180,5 ± 1,57) og 8 kvinner (21,7± 1,7, kroppsvekt 62,6 ±7,1 og høyde 169,7 ± 3,6). Forsøkspersonene utførte fire forskjellige tester. Hver test varte i maksimalt 6 min og 20 sek. Hver kondisjon besto av en trinnvis innledende og omvendt rekkefølge av ekstern belastning. Ved starten av hver test, startvekt på ekstern belastning på 500g. Fra denne startvekten ble det lagt til 500g hvert 20 sekund til maksimalt 5kg på 3 minutt.
Resultat: Det var en overlapping i power av de forskjellige underteknikkene som viser at minimumseffekten av bruk i DG var betydelig lavere enn maksimal STF ($p<.001$), samme for minimum STF og maksimal ST. Det var en statistisk signifikant effekt mellom stigning og valg av teknikk ($p<.001$), men ikke signifikant mellom hastighet og valg av teknikk ($p=.521$). Det var en signifikant effekt av hysterese i overgangen mellom opp- og nedprotokoll i teknikkskift mellom ST of STF i kondisjonene 10 km/t og 8% stigning ($p=.012$) og 12 km/t og 8% stigning ($p=.004$). Den samme effekten ble funnet for STF til DG på 10 km/t og 5% stigning ($p=.024$).
Konklusjon: Hovedfunnene i denne studien er at belastning spiller en rolle i teknikkbruk, men ser ikke ut til å fungere som en kontroll parameter. I noen forhold ser den ytre belastingen ut til å fungere som en kontrollparameter, i det minste for overgangen mellom STF til ST. Hastighet påvirket ikke motstandskraften; mengden ekstern belastning var den samme som utøverne byttet fra STF til ST. Det samlede utfallet indikerer at stigning påvirker valg av teknikk i en større grad enn hastighet.

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Acknowledgments

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1. Introduction

In cross-country skiing during both training and competition, different sub-techniques are used mostly depending on terrain. On national level during a 10 km classical race, athletes changed between sub-techniques on average around 300 times [(1)]. The different techniques can be considered as a gear system that helps the skier adapt to changes in incline and speed [(2)]. Similarities can be drawn to the different forms of gait (walking and running), that are preferred at different speeds. The parameters that can trigger transition in walking are well studied. Mechanical stress [(3, 4)], metabolic rate [(5, 6)], and the subjective feeling of comfort [(7-9)] are all parameters that are suggested to trigger a transition when reaching a specific value.

In the classical style there are three main techniques; diagonal stride (DS), double poling (DP) and double poling with kick (DK). DS is similar as walking and running, where the legs and arms move in a coordinated contralateral diagonal pattern, and are generally used in moderate and steep uphill [(10)]. DP is a dynamic flexion movement of the trunk and the force is exerted throughout the poles [(11)]. While as the legs contribute with an upward movement through enhancing the knee- and ankle joints that elevate the center-of-mass that results in an increased potential energy [(11-13)]. DP is regularly used when the terrain is mostly flat and slight uphill or downhill. DK is performed with a similar upper body movement and poling action as in DP, but propulsion is supported by either a right or left leg kick. So DK can be described as a combination between DP and DS, and is generally used in slightly uphill or in flat terrain when snow condition cause resistance [(14)].

As for walking and running, a number of factors have been suggested that trigger technique transitions in XC-skiing, such as power fluctuations, limitation of pole force, physiological factors. Yet, it is debatable if only one mechanism can explain the different transitions. At steep incline, the potential for utilizing the body's potential energy during DP seem to be reduced. Pellegrini et al suggested that there may be a limitation of pole force which an athlete would want to exceed. With incrementing incline, preference of sub-techniques where lesser pole force is provided, i.e. DS and DK would trigger a change in sub-technique. Yet, at high speeds, thrust time, continuous gliding of the skis in DP are more likely factors of importance. Ettema et al found that fatigue had no, or little, effect on technique choice, so physiological (organismal) factors would unlikely play a significant role.

The relationship between terrain characteristics (mainly slope and obtained speed at moderate intensity) and preferred technique is well known. However, since slope and obtained speed are inversely related, it is not well established which of these external factors dominate in the choice of sub-technique. Even less so it is still a debate which mechanisms (and control parameter) trigger the change of technique with changing external conditions [(15, 16)]. *Cignetti et al.*[(17)] investigated the transition between techniques in classical cross-country skiing by letting the athletes ski as "normal" as they could with roller-skies on a treadmill. The speed was set at a constant 10 km/h with the steepness of the treadmill changing by 1° every 30 s. They found that the skier was attracted to much lower frequency ratio, and anti-

phase and in-phase relation, and that this led the skier to lose stability through transition between these attractor states from an increased incline [17].
Pellegrini et al.[10] used the same setup for the test as *Cignetti et al.*[17] but as an extension they varied the speed at constant incline. They tried to find the trigger parameter regarding transition in techniques in classical roller-skiing. The skiers changed technique from DP, to DK and then to DS when the steepness raised, but when speed increased all skiers preferred to choose DP. They suggested that the selection of technique was mainly steered by a threshold for poling force. They found that in high speed the leg-thrust time is to low, and therefore the use of DK and DS will limit the propulsive phase. *Ettema et al*.[16] and *Løkkeborg et al.*[15] found that incline seemed to have more of an influence on the choice of technique more than speed had.

Changing both speed and incline gradually, with constant workload has been done previously from *Ettema et al.*[16]. *Løkkeborg et al*.[15] did all with changing incline, speed and workload, keeping two of the parameters constant. What is still lacking is a condition where workload changes gradually but independent of incline and speed, i.e. keeping these parameters unaltered. This is an important missing analysis, because the latest study from *Løkkeborg et al.* [15] revealed that the role of incline, speed and workload may be condition dependent and entangled.
The purpose of this study is to investigate if external workload will have impact on the spontaneous change in technique in classical cross-country skiing. Workload was regulated by changing a resistant force on a rope attached to the pelvic region of the skier. Thus, exact workload was uncoupled from the speed and incline combination. By applying this setup at different (but constant) incline-speed combinations, we can identify is workload at technique change is dependent on any speed-incline condition, i.e., if workload is to be considered a key factor (control parameter for technique change).

2. Method

2.1 Participants

14 male and female cross-country skiers participated in the study, see table 1. for demographics. The participants were students from NTNU, some of them were familiar with roller-skiing on a treadmill.

All participants signed a written consent, and they were informed that they could withdraw from the project at any time without giving any reason. This study was registered, assessed and approved by Norwegian Social Science Data Services (NSD). The study was conducted in accordance with the Declaration of Helsinki

Table 1: Anthropometric and performance characteristics of 6 males and 8 females (mean±SD)

	Men	Women
Age (years)	24.1 ± 2.1	21.7 ± 1.7
Body mass (kg)	77.6 ± 4.4	62.6 ±7.1
Height	180.5 ± 1.7	169.7 ± 3.6

2.2 Experimental design

The test where done in one-hour inclusive warm-up. The participants started with both height and weight measure. The tests were done with four conditions, with different combination of two inclines and speeds leading to overlapping powers when adding resistance force, with classical roller-skiing on a treadmill. Roller-skiing on treadmill was chosen to control these conditions, to ensure standardized test execution, and allow for manipulation of workload.

2.3 Instruments

The participants skied on a motorized 5 x 3-meter treadmill (Forcelink Technology, Zwolle, Netherlands), that is optimized for roller-skiing. All participants used the same pair of roller-skies with rolling resistance category 2 from IDT (IDT sports, Lena, Norway). The participants were allowed to use their own poles, or Swix Quantum 1 (Lillehammer, Norway) provided in 5 cm length intervals. A purpose-made resistance pulley system was used to apply different resistance force on the rope attached to the skier (see fig. 1). Small 500 gr sand-filled bags were added and removed according to protocol (see fig. 2) to obtain the desired workload.

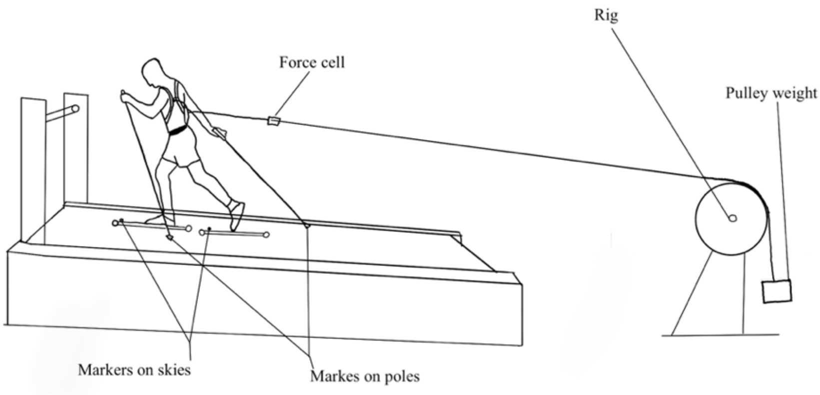

Figure 1: Illustration of the experimental setup

2.3.1 Kinematic variables and technique identification

The kinematic data were continuously collected during the protocol executions with Oqus 3D motion capture system (Qualisys AB, Gothenburg, Sweden). Eight cameras recorded seven passive reflective markers in a sampling rate of 200 Hz. One marker on each pole (two centimeters above the pole tip), one on each ski (at the front side), one on the back of the participant (pelvic region), and two on the treadmill in longitudinal direction. Markers on the poles were used to check the speed, and markers on the treadmill to check the incline. The volume the skier was able to move in was calibrated according to QTM guidelines with a wand with a known length and a L-frame were used to calibrate the 3D-system and were calibrated to each participant (0.72±0.07). A force cell was attached between rope and waist belt (Fig.1), recording continuously at 1500 Hz and synchronized with the motion capture data.

Sub-techniques were identified using a purpose developed algorithm (Ettema 2017) in MatLab (9.7.0, R2019b, Mathworks Inc., Natick, MA, USA). In short, the algorithm identifies the sub-technique through the relative phase between the ski-cyclic movements. The choice of technique was also recorded manually under each test to verify the algorithm [16].

2.4 Test protocol

All participants completed a 10-min warm-up to get familiar with the treadmill with varying incline and speed to ensure that each sub-technique was used during the warm-up. The participants also warmed-up to ensure that the roller-skies were properly warmed up. The participants were explained about the duration, and general design of the experiment (a.o., speed and incline for each condition), and that they were free to choose any sub-technique at any time that felt most natural. Both speed and incline were constant under each condition, based on the previous findings from *Ettema et al* [16] and *Løkkeborg et al.* [15, 16], this was to ensure submaximal load, reasonable expectation that all or at least two techniques were used, and that there was an overlap in workload between the conditions. Also, they were designed to be at a speed and incline where it was not expected to start with DS.

Table 2: Overview of the different test (speed, incline and Watt)

Initial workload (W)	**Incline (%)**	
Speed (ms^{-1})	**5**	**8**
2.78	140	190
3.33	160	230

Each condition consisted with an incremental initial and reversed order of external load. With using external load, speed, and incline we were able to isolate one of the parameters and be able to see which parameter could influences the most.

Each test lasted maximally 6 min and 20 sec, the length of the test depended mostly on when (and if) the participant chose DS (the 'lightest end-gear'). In case a participant chose to apply DS, a last additional 500g was added to establish if that choice was persistent. At the start of each test, an offset external load of 500g was applied to ensure the rope from the participant to the pulley weight was tight. From this onset load, 0.5 kg was added every 20th second, up to a maximal of 5 kg at 3min, see figure 1

At 2,78 m/s (10 km/h) this implied an increase of 13,7 watt for each 500 g, and at 3,33 m/s (12 km/h) an increase of 16,3 watt.

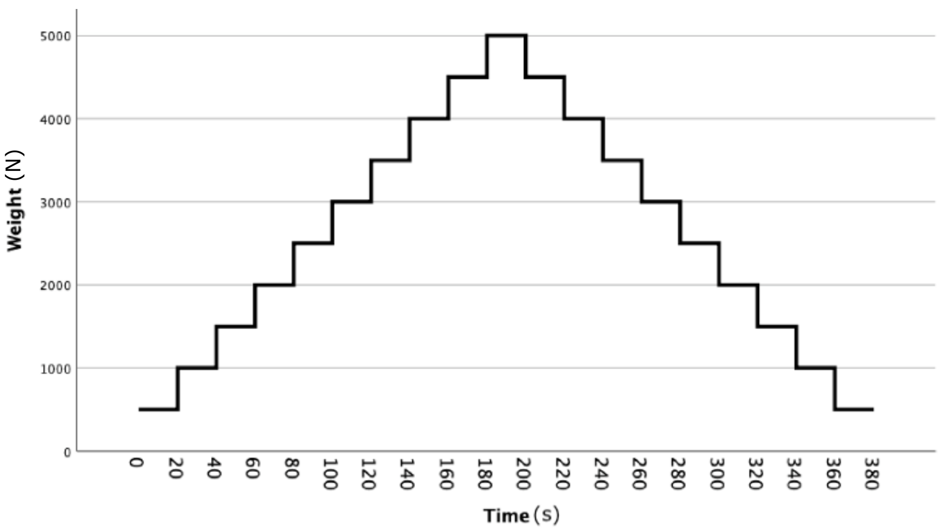

Figure 2: Overview of the 'upward' and 'downward' protocol of added weight.

Each participant started with first condition at 10 km/h and 5% incline (V10I05), so they would be familiar with using the pulley weight. The rest of the tests were quasi-randomized. After each test, the participants were given a 5 min break.

2.5 Statistical and data analysis

All statistical analysis was done in Microsoft Excel for MAC (Excel 2020, 16.36, Microsoft Corp., Redmond, WA, USA) and Statistical Package for the Social Science (SPSS 27; IBM Corp., Armonk NY, USA). All data were tested for normality by using a Shapiro-wilk test. For the main analysis, i.e., comparing effect of speed and incline on the power and force at technique change, many of the data sets were not normally distributed (from a Shapiro-Wilk test). Therefore, this analysis was done using a Wilcoxon signed rank test.

Regularly, an athlete would use all technique transitions during some but not all protocols. For the main analysis, such behavior would result in a 'missing data point', even though all test results were valid and available. Such 'missing data' events were filled in by assuming a hypothetical transition one extra 500g load change beyond the executed protocol. This data expansion increased the statistical power and added valid data when using a Wilcoxon signed rank test: the hypothetical power and force were always the most extreme (maximal or minimal) value in a protocol; the exact value is not taken into account in the Wilcoxon test. The Wilcoxon test does not opt for a 2x2 (speed-incline) analysis. Thus, four separate comparisons were made (two speed comparisons at two inclines and two incline comparison at two speeds). The alpha for significance was set at 0.05 and not adjusted to account for multiple testing. However, care was taken during the overall interpretation (discussion) for that reason.

It should be noted that like previously studies done by *Ettema et al.*[16] and *Løkkeborg et al.*[15, 16], the statistical outcome is reversed in the sense that non-significance indicates identification of a 'control parameter' role. If there is no statistical effect of the parameter tested (incline or speed) on the two shifting parameters (force and power at technique transition), this would suggest a 'control parameter' role of the shifting parameter for choice of technique. For example, if at two different speeds (at the same incline), athletes would shift technique at the same resistance force, this would appear as a non-significant impact of speed on the force of shift. In other words, the 'burden of proof' is reversed: significance shows the variable at hand does not have a 'control parameter' role; non-significance is not proof of the opposite but may indicate it.

Overlap in power ranges for the three techniques was tested comparing the minimum and maximum used power at the given technique with a Paired T-Test. To see proportion of use of techniques within the different conditions, was different between constant speed and incline, a Wilcoxon Signed ranked test was used.
To check for hysteresis in the direction in protocol, difference in power between both shifts in technique from 'up' and 'down' protocol, a Wilcoxon Signed rank test was used. To check for hysteresis in the direction in protocol, difference in force between both shifts in technique from 'up' and 'down' protocol, a Wilcoxon Signed ranked test was used.

2.5.1 Calculation of work rate

The total power (P) was obtained as the sum of P_g (power by gravity) P_f (power from roller friction) and P_p (power from pulley weight).

$$P_g = m * g * \sin\theta * v$$
$$P_f = m * \mu * g * \cos\theta * v$$
$$P_p = m_p * v * g$$

$$\mu = \frac{F_f}{N}$$

Where v is speed on the treadmill in m/s, m is the body mass of the participant, g the gravitational acceleration, m_p is the mass of the pulley weight, θ is the incline in degrees, and μ is the friction coefficient from the wheels on the roller skies.μ was established by using the same protocol as *Sandbakk et al*.[(18)].

3. Results

All participants changed from either DP-DK, or from DK-DS, no participants changed directly from DP-DS. Two participants did not use all three sub-techniques of interest in all conditions. If the participants didn't employ a given technique shift one of the tests to be compared, and thus is not to be considered a factor closely linked to a control parameter. Changes in technique occurred within a few seconds of each change of external load. If there appeared to be a significant effect on the constant parameter, this indicates indicate that the outcome is influenced at the given subset, and thus is not to be considered a factor closely linked to a control, parameter.

3.1 Use of technique

An overview (mean for all condition) of the data shows there is an overlap in power between the different sub-techniques, meaning that the minimum power of use in DS was significantly lower than maximum DK, the same effect was found in minimum DK and maximum DP. Minimum DS was very similar to maximum DP, and showed no significant difference (.438) (see fig. 3).

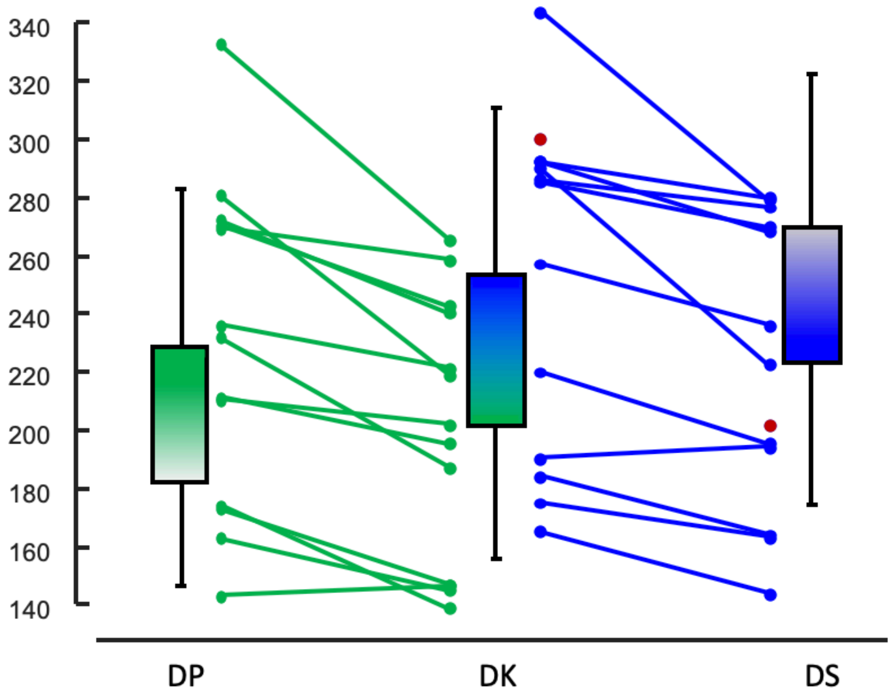

Figure 3: The green and blue bars show the mean (with SD) of minimum and maximum power obtained for the techniques. The blue-green coding is to link the individual data to the aspects of the bars. Red markers are those with no companion to compare. (n=12)

At 'high' inclines the athletes tended to use lower gear independent of speed. Same pattern was seen in 'lower' inclines where the athletes used a higher gear. On average (for all protocols) the techniques were used DS 0.41, DK 0.33 and DP 0.26 There was a statistically significant interaction effect between incline and choice of technique on the combined dependent variables (p=<.001), but not significant between speed and choice of technique (p=.521) (see figure 4). Two outliers was excluded from analysis in total use of technique, where one participant only used DS (100%) in all condition, and one participant that used DK and DP in all conditions (DK=44%, DP=56%).

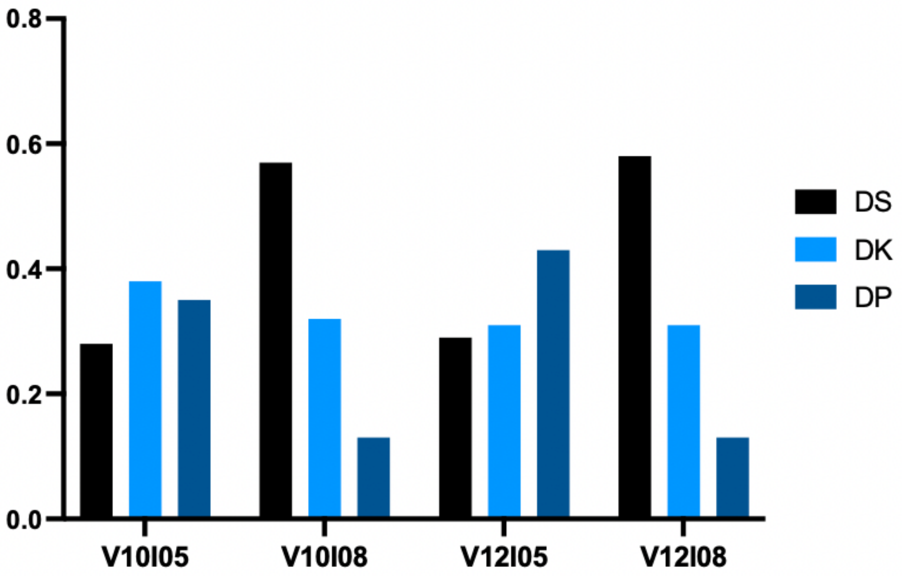

Figure 4: Choice of technique in each condition. The error bars were excluded from the figure, because there were some athletes that always didn't, or always, used one technique for the whole condition. (n=14)

3.2 Effect of power and force

Table 4 shows the effect of power and force on constant incline and speed. The non-significance of the comparison indicates a comparable force, unaffected by speed. The change in force in transition from DS-DK is borderline (see table 4). The effect of force on incline was significant in both shifts. Force at shift differs at different inclines. Both incline and speed had a significant effect on the power at shift, except for incline at V10 (see table 3.).

Table 3: Statistical outcome from Wilcoxon Ranked Signed test on differences on two conditions with constant incline and speed. n indicates how many participants were used in each analysis. eta is the effect size

		DK-DP			DS-DK		
Power		p	n	eta	p	n	eta
Incline	V10	.128	7	.407	.005	10	.627
	V12	.028	6	.635	.003	11	.626
Speed	I05	.015	9	.572	.002	12	.624
	I08	.043	5	.640	.005	10	.627
Force							
Incline	V10	.018	7	.632	.009	10	.581
	V12	.046	6	.575	.004	11	.607
Speed	I05	.515	9	.154	.084	12	.352
	I08	.345	5	.298	.093	10	.376

3.3 Hysteresis

There was a significant effect of hysteresis in transition between up and down protocol in technique shift DP-DK during condition V10I08 and V12I08. The same effect was found in one of the conditions for DK-DS, V10I05. Athletes switch back to both DP and DK at a different weight in the 'down' protocol and the 'up' protocol, with both a higher and lower weight.

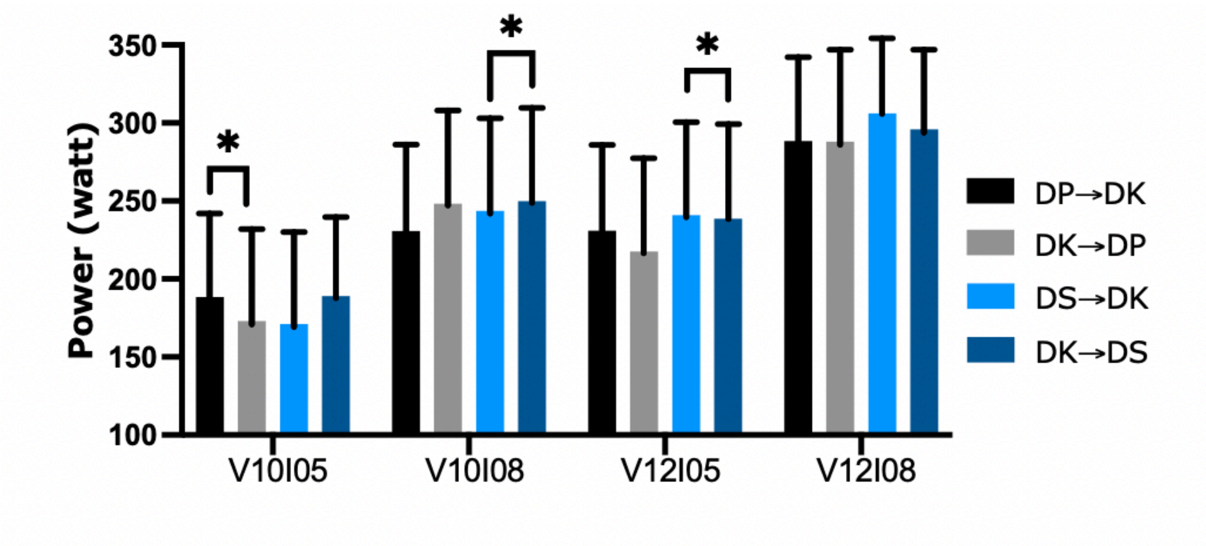

Figure 5: Mean power at shift between techniques of all athletes. (= p<.0.5) (n=14)*

4. Discussion

The purpose of this study was to investigate if power is a control parameter (or a factor tightly linked to such parameter) for choice of technique. The main findings of this study are that power plays a role in technique use but does not seem to act as a control parameter. First, there was an overlap in power ranges where the three sub-techniques were used. In other words, at one particular power, at least two different sub-techniques were applied by the same athlete, depending on the protocol. When comparing protocols directly by Wilcoxon ranked sign tests, the power at which a transition was made also differed. On the other hand, in some conditions, the resistance force, which was used to regulate power, seems to act as a control parameter, at least for the DK-DP transition. That is, at a given incline but different speeds, the athletes tended to shift technique at a similar resistance force (yet different power and speed). This applied to both inclines that were included in the protocol. However, this was not the case when different incline protocols at one given speed were compared.

4.1 Influence of power and pulley force

When investigating if power is a control parameter, we found that by adding external resistance load to the athlete, power was changed without a change in speed or incline. It should be noted that, even though power (and resistance force) protocol-wise can be regarded as the independent variable, and technique transition occurrence the dependent variable, with regard to statistical analysis and interpretation, these roles were swapped [15, 16]. Thus, we looked at the shift in two protocols with speed and incline (x), and compared the outcome, power and force (y). The power at technique transition was affected by both speed and incline, indicating that power is not (tightly linked to) a control parameter.

Power and force are closely but not completely linked to each other. From our data, we found a clearly different outcome when running comparisons for power and force. Speed did not affect the force of transition; the amount of external load was the same at which the athletes switched from DK to DP. For DK-DS statistically the same (non-significant) result was found, but the results still showed a weak tendency of the speed effect on force at technique transition. When protocols at different inclines were compared, the analysis for force and power was very similar. All comparisons showed clear force differences. Thus, when incline changes, the athletes do not shift at the same resistance force. This could indicate that force could be a control parameter when speed is not constant. Since there are no other studies on this, this needs further investigation.

The overall outcome indicates that incline is a stronger determinant for choice of technique than speed, as in agreement with earlier studies [10, 15, 16], and for constant speed [10, 17]. During both conditions at 12 km/h, all 12 athletes used DP at 5% incline, against only five out of 12 used it at 8% incline. The same pattern was during both condition at 10 km/h, whereas all athletes applied DS at 8%, and at 5%, eight athletes used it. This shows that at a higher incline the athletes tend to use a lower gear, even if the speed changes. Still there are still no clear external mechanism that leads to a shift in technique. Seemingly there are more internal mechanisms that can steer shifts.

4.2 Hysteresis

From theories in motor control, it's expected that hysteresis is to occur in transition of gait. Implying that change of technique is affected by direction of change [(19)]. In our setup, a difference in force (and power) was expected between the 'UP' and 'DOWN' part of the protocols. Such hysteresis was only found in one of four condition for DK-DS, and in two out of four in DP-DK, and a borderline for one condition in DP-DK. Also, when setting the differences at 0, i.e. no differences occur. Neither does using the exact outcome (which could have been noise) does not make a difference on the statistic result.

In all conditions, eight athletes did not change back to DP after starting at that technique, which was considered as a hysteresis effect and data included in the analysis. Every athlete that employed both DS and DK in each condition had a lower minimum power in DS than in DK, while the same outcome was found in minimum DK and maximum DP. This could indicate that there was a hysteresis effect in overlap in power between powers.

Some of the athletes reported that certain conditions were quite hard. However earlier studies it has been shown that fatigue doesn't have any, or little, influence on choice of technique [(20)]. They also said that in condition at 12 km/h at 8% incline, it was a bit of discomfort when using DS because of the high speed. Saying that they were unable to execute the technique as they wanted. This could be because the athlete had the feeling that they weren't able to change technique. As the athletes reported that they changed later as a result of a change in technique were too demanding at an earlier stage. Even though this protocol was set up to avoid this by having a high load, and short durance. To analyze this in the future this needs to be done in a reversed order, to start with a height weight, go down, then up again.

4.3 Protocol

At a given force, the differences in power are larger for the slope comparison (the same for force would have given 60-70 W difference), compared to comparison in speed (30-40 W difference). A potential effect on the outcome of this skewness in the design should be considered. The impact on power of shift is of no relevance because the outcome was similar in all comparisons. However, force of shift is affected by incline, not or marginally by speed. One may argue that at different inclines athletes could have made a transition in technique at similar resistance force (which was not the finding), if the corresponding power differences would have been similar to the differences when comparing different speeds (i.e., 30-40 W instead of 60-70 W). In other words, the finding that force functions as a control parameter at constant incline, but not at constant speed must be interpreted with caution.

The same issue may play a role in previous studies, that the differences in power at a given force, are larger for the slope comparison compared to speed comparison. This may have played a role when we compared speed and incline. Thus, the same issue may play a role in previous studies [10, 15, 16], which indicated that incline is more influential than speed on the occurrence of shift in technique. This may be due to that the inclines used in these protocols (and in practice) have a larger impact on power than speed.

Athletes in this study tended to use DK at a same rate as in other studies, in this as in other studies, athletes tend to use DK as an "transition gear" from DP to DS [15, 16]. The data showed that the athletes used DK from 33-41% of each condition, in some conditions more than both DS and DP. This could be due to the advantages from using more of the lower body power to 'drag' the pulley weight, as *Göpfert et al.*[21] showed that DK increased cycle length and cycle rate that generated a higher leg and pole force in shorter propulsion time.

4.4 Methodology

Full friction roller skis were used, this may influence the usage of a different technique. This may have had some implications for the choice of technique, no athletes went from DP to DS, as have been seen in earlier studies [15-17]. When skiing on snow many athletes change directly from DP to DS due to more rapidly changing inclines that demands quicker changes in technique.

Because the intensity was regulated by a given increase in resistance fore, power levels that were obtained did not necessarily correspond equally between protocols. This makes the interpretation of the statistical findings somewhat cumbersome. However, mean and median power differences at technique transitions between the protocols were clearly higher than the power offsets that occurred between protocols, and thus cannot explain the outcome. In other words, the interpretation presented in the discussion (i.e., power is not regarded as tightly coupled to a control parameter) is regarded as valid. This problem does not apply to the analysis of resistance force.

5. Conclusion

This study shows that power has influences change in technique but seems not to be a control parameter. Force seems to act as a control parameter at constant incline and changing speed, but not at constant speed with changing incline. When differences in power become large, force cannot function as a distinct control parameter. On the other hand, incline seems to be a stronger determinant for choice of techniques than speed. Further study with similar differences in power on both incline and speed is needed to examine whether incline could be the steering parameter.

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