Mastergradsoppgave

Is laterality, intensity or strength asymmetry associated with the preferred side in the G2 skating technique in cross-country skiing?

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SAMTYKKE TIL HØGSKOLENS BRUK AV MASTEROPPGAVE I KROPPSØVING

Forfatter: Simen Thorrud

Norsk tittel: Er lateralitet, intensitet og styrke asymmetri relatert til preferert hengside i langrennsteknikken padling?

Engelsk tittel: Is laterality, intensity or strength asymmetry associated with the preferred side in the G2 skating technique in cross-country skiing?

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underskrift

Norsk sammendrag

Formål: I langrenn utføres skøyteteknikken padling (G2) med asymmetrisk kraftimpuls i staking, synkront med skøytefraspark (hengside), men uten staking på andre siden med bare skøytefraspark (friside). Anekdotiske bevis indikerer at langrenns utøvere på høyt nivå klarer å henge til begge sider uten vanskeligheter ved lave og moderate intensiteter. Videre, når intensiteten øker, henger de bare til én side. Målet med denne studien å undersøke om denne skjevheten hos langrenns utøvere, er relatert til generell lateralitet, intensitet, muskelstyrke- og kraft asymmetri. **Metode:** 15 mannlige langrennsløpere ble testet i maksimal kraft og effekt i over -og underkropp, på høyre og venstre side i ulike styrketester. Generell lateralitet ble testet via Edinburgh Handedness Inventory og Waterloo Footedness Questionnaire-Revised. Lateral preferanse i langrennsteknikken padling (G2) på fem forskjellige intensiteter, fra lav til maksimal spurt, ble vurdert gjennom en fem-poengs skala: fra alltid venstre, venstre, ingen preferanse, høyre, alltid høyre. I tillegg vurderte subjektene hvor godt de mestret padling på preferert og ikke-preferert hengside, på en 10-punkts skala på fem forskjellige intensiteter. **Resultat:** Det var signifikante forskjeller i graden av mestring ($p<0.05$) mellom foretrukket og ikke-foretrukket hengside for alle intensiteter. Mestring av ikke-foretrukket hengside ble redusert når intensiteten økte, og det var signifikante forskjeller ($p<0.05$) mellom alle intensiteter, bortsett fra for de to laveste intensitetene. Lateral preferanse i padling (G2) var ikke relatert til verken håndpreferanse ($r= 0.240$) eller fotpreferanse ($r= 0.274$). Det var ikke signifikante forskjeller i kraft- og effektvariabler mellom preferert hengside og friside ($p>0.05$). **Konklusjon:** Denne studien viser at langrenns utøvere har en preferert hengside og at denne preferansen blir sterkere når intensiteten øker. Langrennsutøvernes mestring av preferert hengside holder seg stabil på tvers av alle intensiteter, men mestring av ikke-preferert heng-side reduseres når intensiteten øker. Det var ingen klar sammenheng mellom generell lateralitet, styrke eller effekt og hengside-mestring av padling i langrenn. Lateral preferanse i padling er oppgave spesifikk og er ikke knyttet til generell lateralitet eller langrenns utøvernes styrkeasymmetri.

Nøkkelord: lateral preferanse, elite utøvere, langrenns utøvere, handedness, footedness.

Abstract

Purpose: Laterality, or limb dominance, is a well-known feature in both humans and animals. In the cross-country skiing G2 skating technique, skiers use an asymmetrical loaded double pole push synchronous with one leg push (strong side), but without poling on the other leg push (weak side). Anecdotal evidence indicates that most elite skiers manage to use both sides without difficulties at low and medium exercise intensities. However, when the intensity increases, skiers show a greater bias towards one side. Therefore, the aim of this study was to examine whether this bias is found in elite skiers, if it is related to exercise intensity and the association with laterality, muscle strength and power asymmetry. **Methods:** 15 male cross-country skiers were tested for upper and lower body maximal strength and power on the dominant and non-dominant side in a number of exercises. General laterality was assessed via the Edinburgh Handedness Inventory and the Waterloo Footedness Questionnaire- Revised. Lateral preferences in the G2 technique at five different intensities, ranging from low to maximal sprinting, were assessed by a five-point scale ranging from always left to always right. Additionally, the subjects rated how well they coped with the G2 on the preferred and non-preferred strong side on a 10-point scale at the five different intensities. **Results:** The degree of coping was significantly different ($p<0.05$) between the preferred and non-preferred strong side for all intensities. Lateral preference in the G2 was not related to either handedness ($r= 0.240$) or footedness ($r= 0.274$). Strength and power variables were not significantly different ($p>0.05$) between the preferred strong side and weak side. Coping of the non-preferred side decreased as intensity increased with significant differences ($p<0.05$) between all intensities, except for the two lowest. **Conclusion:** The current study demonstrates a greater bias towards preferring one side in G2 skating among cross-country skiers, and that this bias increase as intensity increases. The athletes' coping of the preferred strong side remains stable across all intensities, whereas coping of the non-preferred strong side decreases. There were no clear patterns of laterality, strength or power related to the preferences in G2 skating. Thus, lateral preference in the G2 is task specific and is not related to laterality in general or the athletes' strength asymmetry.

Key words: lateral preference, elite athletes, skiers, handedness, footedness

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1 Introduction

Cross-country ski skating consists of quadrupedal locomotion patterns involving several modes of interlimb coordination, both symmetrical and asymmetrical movement patterns. In the cross-country skiing G2-skating technique, cross-country skiers use an asymmetrical loaded double pole push synchronous with one leg push (strong side), but without poling on the other leg push (weak side) (Nilsson, 2004, Smith, 2003). The G2-skating technique is used under conditions where there are large resistive forces like uphill or in horizontal terrain with high glide friction. In a cross country ski race approximately one third of the course is uphill, and about half of the competition time is spent in the uphill terrain (Kvamme et al. 2005). Anecdotal evidence indicates that most elite cross-country skiers manage to use both sides without difficulties at low and medium exercise intensities. However, when the intensity increases, skiers show a greater bias towards one side.

Previous research concerning force production between the left and right body sides in the G2-skating technique suggests a higher poling force on the strong side (Stöggl, 2010; Millet, 1998). However, the evidence is somewhat ambiguous concerning force differences in the legs during G2-skating. Stöggl et al. (2010) found small peak force differences preferring the weak ski. Babiel (2003) reported higher vertical peak force in favor of the weak ski and slightly higher values for the strong ski in mean vertical force during G2. However, Perrey et al. (1998) suggested that the lower limb forces were higher on the strong side, in accordance with previous data of ski forces measured in the G2-skating technique (Smith, 1992; Street, 1995).

Humans have a tendency to preferentially use one hand or foot over the other to perform a motor activity. The preferential usage of this limb usually outperforms the other limb in performance tasks. This tendency characterizes the lateral preference (Serrien et al. 2006). Hand preference seems to be stronger with more complex tasks and is also related to performance (Steenhuis and Bryden, 1989). Asymmetry in hand performance is greater in complex tasks which require accuracy, than in simple tasks like grip strength (Flowers, 1975; Provins and Magliaro, 1993; Borod et al.1984). Further, the performance asymmetry in complex tasks is greater when speed rather than accuracy is stressed (Roy, 1983). The tasks examined in these studies did not only differ in terms of complexity, but also in context of the task. Hausmann et al. (2004) investigated manual asymmetry in both simple and more complex finger movements and found that manual asymmetry performance increase in simple tasks, and decreases with task complexity. Lateral preference in a given skill will induce bilateral performance asymmetry as a result of increased use of the preferred hand (Peters, 1995). Mikheev et al. (2002) revealed that right handed judo athletes preferred to execute certain motor tasks more frequently with their left hand, suggesting that lateral preference is a dynamical feature.

Foot preference is somewhat different and certain tasks tend to cause stronger preferences than other tasks. Peters (1988) definition of footedness involves different roles between the lower limbs. The preferred leg is the leg used to manipulate an object or to lead out during a jump, and the non-preferred leg is the leg used to support the activities of the preferred leg by providing postural support and stability (Peters 1988). Still, there is evidence demonstrating that humans have one preferred leg, and not preferred differentiated roles between the legs. Hart and Gabbard (1997) showed that the preference of the supporting foot depends on the context of the task. The preferred mobilizing leg in bilateral tasks became the supporting leg in a unipodal balance task for over 50% of the subjects. The correlation between foot preferences and performance is higher for skilled actions than for unskilled actions (Kalaycioglu et al. 2008).

Human locomotion like able-bodied gait is characterized by symmetric movement patterns with asymmetries in propulsive force between the limbs. Asymmetries have been thought to reflect limb dominance. During human able- bodied gait the non-dominant lower limb contributes more to support, while the dominant lower limb contribute more to forward propulsion (Sadeghi, 2000). At faster speeds the contribution to propulsion are greater in the dominant limb (Rice, 2010; Seeley, 2008). From a sport specific practice perspective Leroy et al. (2000) attributed gait asymmetries in basketball and soccer players to asymmetric locomotion pattern and muscle development. In contrast, swimmers had symmetrical gait variables. Strength asymmetries between the limbs have been reported in sports with asymmetric movement kinetic patterns like volleyball (Markou and Vagenas, 2006), but also in sports with symmetric movement patterns like running (Vagenas and Hoshizaki, 1991; 1992) and cycling (Smak et al., 1999). Bilateral asymmetric force production is related to neural factors, not differences in mechanical capabilities (Simon & Ferris 2008). Dynamical movements with a fast rate of force development, and multi-joint tasks requiring maximum effort have shown greater bilateral asymmetries in electromyography and force production

(Ball, 2011; Kuruganti, 2008) compared to sub-maximum actions (Carpentier, 1999) indicating that load and velocity may influence neuromuscular laterality. Bilateral strength imbalance is associated with a higher injury risk (Knapik et al. 1991; Markou and Vagenas 2006; Yamamoto 1993). Bahr et al. (2004) reported a high prevalence of low back pain among cross-country skiers. Lindsey et al. (1993) proposed that the asymmetrical skating style in cross country skiing was probably responsible for the high prevalence of sacroiliac joint dysfunction found in elite cross-country skiers.

Cross-country skiing is a whole-body exercise that relies on propulsion from both arms and legs. Although asymmetric techniques are used in cross-country skiing, and side preferences are observed; little research has explored lateralization in cross-country skiers. This consideration leads to the question whether the lateral preference of the limbs has an influence on the preferred strong side in the G2 skating technique. Therefore the first objective of this study was to examine if cross-country skiers have a preferred strong side in the G2 ski skating technique, if the preference is related to lateral preference in general, and moreover how is this preference across exercise intensities. The second objective was how athletes' skill of the G2 ski skating technique is influenced by different exercise intensities. Finally we also aimed to elaborate the relationship between preferred strong side in the G2 ski skating technique and muscle strength and power asymmetry. It was hypothesized that 1) cross-country skiers have a preference toward one side and that this preference is related to laterality; 2) the athletes' skill of the G2 ski skating technique decreases as intensity increases; and 3) consistent asymmetrical workloads, as in the G2 ski skating technique, induce muscle strength and power asymmetries in cross-country skiers due to the degree of the preferred strong side that is more frequently applied.

2 METHODS

Design of the study

Fifteen male cross-country skiers were tested to examine the relationship between preferred strong side in the G2-skate technique and laterality, exercise intensity, upper and lower body muscle strength- and power asymmetry. The muscle strength and power tests; single arm pull down, single leg countermovement jump, lateral jump, isometric mid-thigh pull clean were performed in a random order, during one day. The subjects were familiar with the movement patterns in the test exercises as they frequently used these in everyday training. The subjects were given specific instructions how to carry out the exercise prior to each test. The measurement of lateral preference were tested 4 weeks later, trough the Edinburgh Handedness Inventory (Oldfield, 1971) and the Waterloo Footedness Questionnaire-Revised (WFQ-R) (Elias et al., 1998) , together with a structured interview about their lateral preference for the strong side in the G2-skate technique.

Subjects

Fifteen male cross-country skiers volunteered to participate in the study. All subjects were competitive cross-country skiers on a national level in Norway. Five subjects had competitive experience from the Cross-Country FIS World Cup. None of the subjects had suffered from injury within the last six months leading up to the study. The subjects were given oral and written information concerning test procedures and possible risks before they gave their written consent to participate in the study. The study was approved by the Regional Ethics Committee of Midt-Norge. Physiological and anthropometrical characteristics of the subjects are given in Table 1.

Table 1. Physiological, anthropometrical and training volume characteristics of the 15 male cross-country skiers before entering the study.

Variables	**Mean ± SD**
Age (years)	24.3 ± 4.6
Height (cm)	181.3 ± 5.4
Body weight (kg)	78.6 ± 7.9
VO_2 max (ml·kg^{-1}·min^{-1})	74.3 ± 5.3
Training volume last year (hours)	574.8 ± 88.3

Test Procedures

The subjects were instructed to warm up for 15 minutes on a level treadmill prior to the muscle strength and power tests. The exercise intensity was light to moderate, on a self-selected speed ranging from 7-12 km/h with a heart rate at approximately 60-70% of maximum heart rate. The subjects performed the muscle strength and power tests in a random order.

Single arm pull down:

The subject was instructed to sit approximately 2 meters from a pulley system with legs and hips locked in a fixed position, on a modified cable pulley system (Hoff et al. 1999). In order to assess poling, the subjects performed the pull down with right and left hand separately. When the subjects were properly situated, the test leader placed the handle of the pulley system in the subject's hand and positioned the hand in a position similar to the starting position of a poling action. The special warm up routine was performed with a weight of 5 kg for 6-8 repetitions, and 7 kg for 3 repetitions on each arm with 3 min rest between the warm up sets and the maximal poling power test. On the command of the test leader, the subject pulled as forcefully as possible until the hand touched a pad approximately 10 cm behind the hip. A successful repetition was considered when the subjects' hand touched the pad, and the elbow joint angle was extended more than 90°. The subjects performed 1 single repetition with a weight of 10 kg and 15 kg 3 times on both arms. Each trial was separated by 3 min recovery periods. A force transducer (Muscle Lab, Ergotest Technology a.s, Langesund, Norway) was attached to the weight stack in order to assess peak power.

Single leg Countermovement Jump:

In order to assess lower body vertical explosive power, single leg countermovement jump (CMJ) was performed on a Kistler force plate platform (Kistler 9286AA, Kistler Instrument Corp., Winterthur, Switzerland) (Newton et al., 2006). The subjects performed 3 repetitions of self-administered sub-maximal CMJ on right and left leg as a warm up. When performing the CMJ, the subject kept his hands on his hips and started in an upright position. The subject was further instructed to squat down and immediately engage in a vertical jumping motion in order to use the muscles elastic properties. The subject initiated the CMJ on his own volition. The CMJ was performed for 3 repetitions on each leg, with one jump separately on the right and left leg. Each leg trial was separated by 3 min recovery periods.

Single leg lateral jump:

The subjects' ability to generate horizontal power was assessed by carrying out a one leg horizontal lateral jump. Stöggl et al. (2011) suggests that an altered form for squat movement, with a lateral push-off, might be suitable for investigating different skating techniques. The subjects performed 3 repetitions of self-administered sub-maximal lateral jump on right and left leg as warm up. The subjects were instructed to start with the designated foot on a line with the hands on the hips, and thereafter jump with maximal effort in the lateral plan and land on two feet. The subject was allowed to self-select the squat depth prior to jumping.

Three repetitions were performed on each leg with 3 min rest between jumps. The distance covered was measured to the nearest 0.01 meter (Meylan et al. 2009).

Isometric mid-thigh pull clean:

To assess the subject's ability to generate maximal voluntary force into the ground, an isometric mid-thigh pull clean was performed on two force platforms (Kistler 9286AA; Kistler Instrument Corp.; Winterthur, Switzerland)(Haff et al. 1997; Stone et al. 2003; Stöggl et al. 2011). The subject performed two maximal isometric repetitions against the force platforms. Before the maximal repetitions the subjects performed two submaximal repetitions. The subject was allowed 3 min of rest between repetitions. Prior to the maximal effort, the subject was placed in a squat rack with adjustable heights for the barbell. Each subject was placed with one foot on each force platform, and their feet under the bar at a knee angle of 144±5° and a hip-angle of 145±3°, measured with a large protractor to ensure similar test conditions for each subject. The subjects were required to maintain this knee-angle and hip angle throughout the duration of the trial. Once in place the subject attached his hands to the barbell with wrist straps, at shoulder width apart. On the command of the test leader, the subject pulled as fast and forcefully as possible against the rigid barbell attached to the ground by static ropes in order to prevent any vertical movement. For each repetition, maximal force and rate of force development were recorded.

The Edinburgh Handedness Inventory:

The Edinburgh Handedness Inventory (Oldfield, 1971) was used to assess hand preference of the subjects. The subjects were asked 10 questions concerning their hand preferences for writing, drawing, throwing, and using different implements like scissors, toothbrush, and knife without fork, spoon, striking matches and opening jars. The subjects were instructed to answer either *always*, *usually* or *both* for the preferred right or left hand in each question. If the subject was insecure about their preference in one of the tasks, the subject was instructed to simulate the actual task. The subjects were given a sheet of paper with the various answer alternatives were they pointed out their concrete hand preference on each question, to prevent any influence from the questioner.

The questioner put «++» in the associated column if the subjects preference were *always* right or left hand, if the subjects preference were *usually* right or left hand the questioner put «+» in the associated column, and if the subject used both hands equally the questioner put a «+» in both columns. The lateral quotient were summed and calculated by adding all the +s for each hand, subtracting the sum for the left from that for the right, and dividing by the sum of both and multiplying by 100 (Oldfield, 1971).

The Waterloo Footedness Questionnaire - Revised:

The Waterloo Footedness Questionnaire – Revised (WFQ-R) (Elias et al., 1998) was used to assess foot preference of the subjects. Half of the 10 item WFQ-R assesses foot preference for the foot manipulating an object (mobilising tasks) such as kicking a ball, smoothening sand, stomping a bug, picking up a marble, and pushing a shovel into the ground. The other half assesses foot preference for the foot providing support during an activity (stabilising tasks) such as standing on one foot, stepping up onto a chair, balancing on one foot on a railway track, hopping on one foot, and first weight bearing foot standing. The subjects were instructed to answer either *always, usually* or *both* for the preferred right or left hand in each question. The subject simulated each task three times to get an objective measure about their preference not only based on their memory. The subjects were given a sheet of paper with the various responses alternatives were they pointed out their actual foot preference on each question, to prevent any influence from the questioner. Responses always left (-2), usually left (-1), equal (0), usually right (1), and always right (2) were summed up and calculated to a footedness preference, following Elias et al. (1998) with the designated foots scoring method, gave the subjects a total foot preference score. The subject was considered to be left-footed if the score was between -20 to -7, a mix-footed with a score between -6 to +6 and a right-footed with a score from +7 to +20 (Grouios et al. 2009). The subjects were also categorized with a mobilising foot and a stabilising foot based on their score in the mobilising tasks and stabilising tasks. A positive score was categorized as right foot preference, and a negative score was categorized as left foot preference.

G2-skate preference assessment

To examine ski specific lateral preference the subjects were asked which side they use as their strong side when they perform the G2-skate technique in the different intensities low, moderate, high/competition speed 15km, sprint competition and maximal speed. The response alternatives with how they usually behave in that specific situation were always left (1), usually left (2), no preference (3), usually right (4), always right(5)". "Always" should be interpreted as 95% or more of the time, "Usually" as 75% or more of the time, and finally

"No Preference" as both hands equally. Additionally the subjects were asked to rate themselves how well they were performed the G2- skate technique in the preferred and non-preferred poling side. The rating consisted of a 10 point scale, were 1 expressed as no coping at all, and 10 were world class.

Data handling and calculations

The trial with the highest value on each limb in the strength tests was used for the analysis. The variables that were analysed included peak power in the 10 kg and 15 kg pull down test with the right and left arm, peak force for right and left leg in the isometric mid-thigh pull clean, single leg countermovement jump height, peak force, rate of force development; max, mean, time to peak power, single leg lateral jump length.

Vertical ground reaction force data were sampled at a rate of 1000 Hz. A special routine was built in Matlab R2007a (The MathWorks Inc., Natick, MA) which calculated the abovementioned strength and power variables. This made it possible to collect force characteristics from right, left and both legs. Figure 1 illustrates the force-time curve of one subject and reflecting force-time curves to all of the subjects.

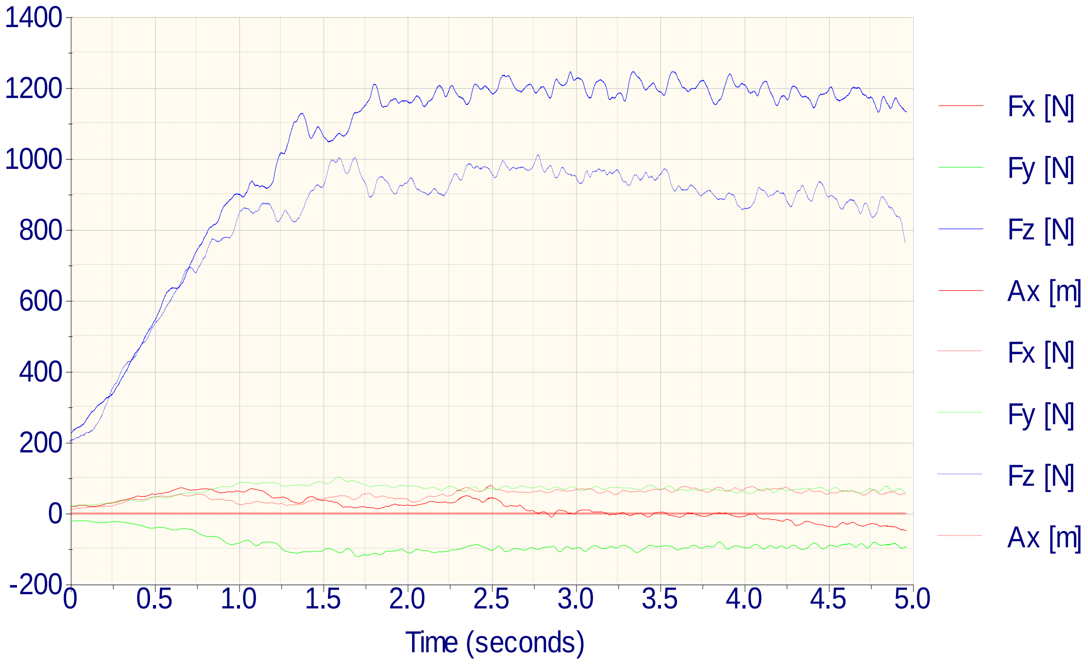

Figure 1. An example plot of leg force as a function of time during the isometric mid-thigh pull clean trial for one subject. Blue curve indicate vertical right leg force development. Scattered blue curve indicate vertical left leg force development. Red curves indicate horizontal force development, and green curves indicate lateral force development.

Statistical analysis

The data is presented as means ± standard deviations (SD). Spearman's rank-order correlation was used to determine whether laterality (handedness and footedness) is associated with preferred G2 strong side. The Friedman test was used to check for statistical significant differences in skill across exercise intensities between the preferred strong side and non-preferred side in the G2-skate technique. Some variables from the maximal muscle strength and power tests were shown not to be normally distributed with a Shapiro-Wilks test. The data from the maximal muscle strength and power tests were pooled to reflect the subjects' respective preferred strong side in the G2-skate technique according to the G2-skate preference assessment. The Wilcoxon signed-rank test was used to check for statistical differences between the G2-skate technique preferred and non-preferred strong side in maximal strength and power. Repeated measurements of the physiological and biomechanical parameters demonstrated intraclass correlation coefficients of > 0.90. Statistical significance was set at α value of < 0.05. All statistical analyses were processed using the SPSS 16.0 Software for Windows (SPSS Inc., Chicago, IL) and Matlab (The MathWorks Inc.,Natick, MA).

3 Results

The subjects displayed a preference towards one side in G2 skating, and this preference increased as intensity increased. Figure 2 illustrate the subjects mean response of preference for the G2 strong side across the respective exercise intensities.

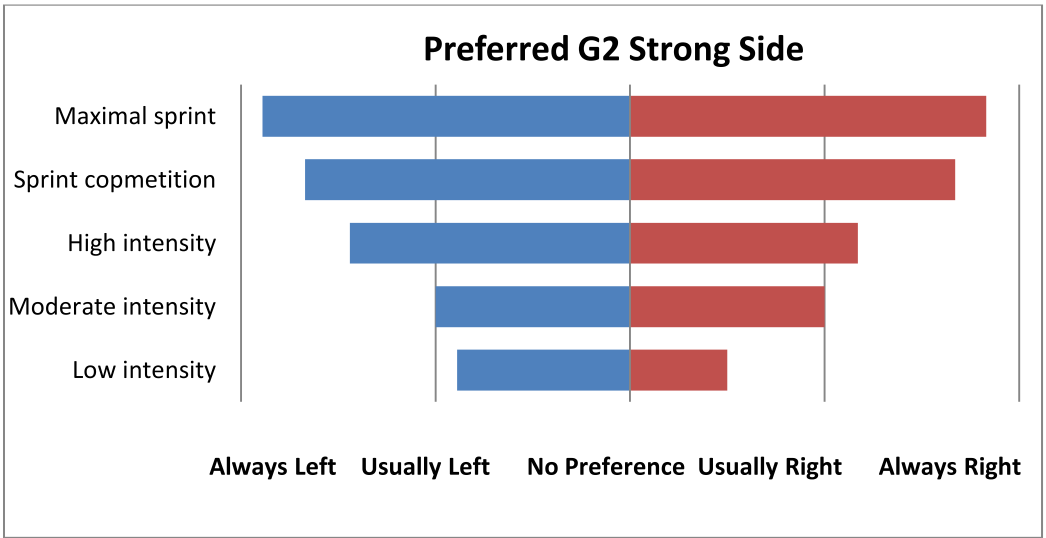

Figure 2. Mean preference for the group of subjects with the preferred left strong side (blue column) or right (red column) for the G2 strong side for the subjects across intensities (n=15)

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Lateral preference in the G2 technique was not related to lateral categorization in the Edinburgh Handedness Investigation (r =0 .240, p= 0.389) or the Waterloo Footedness Questionnaire- Revised (WFQ-R) (r = 0.274, p =0.322). There was however a moderate correlation between preferred G2 strong side and some of the WFQ-R tasks and total WFQ-R mobilising foot score (presented in Table 2.) The lateral preference to kick a ball was related with overall preferred G2 strong side ($p < 0.05$). The preferred foot to smoothing sand was related to preferred G2 strong side in sprint competition ($p < 0.05$), maximal sprint ($p < 0.05$) and overall preferred G2 strong side ($p < 0.05$). The preferred foot to hop on one leg was related to preferred G2 strong side moderate intensity ($p < 0.05$) and high intensity ($p < 0.05$). The preferred foot to help push a shovel into the ground was related to preferred G2 strong side low intensity ($p < 0.05$), moderate intensity ($p < 0.05$), high intensity ($p < 0.05$), sprint competition ($p < 0.05$), maximal sprint ($p < 0.05$) and overall preferred G2 strong side ($p < 0.05$). Total score from the WFQ-R mobilising tasks was related to preferred G2 strong side maximal sprint ($p < 0.05$) and overall preferred G2 strong side ($p < 0.05$).

Table 2. Summary of the Spearman correlation coefficient between lateral preference in G2 strong side during different intensities and lateral preference in the Waterloo Footedness Questionnaire tasks and total score in mobilising and stabilising tasks (n=15).

	G2 Strong side Low Intensity	**G2 Strong side Moderate Intensity**	**G2 Strong Side High Intensity**	**G2 Strong Side Sprint Comp.**	**G2 Strong Side Maximal Sprint**	**Overall Preferred G2 Strong Side**
Mobilising Foot- Kick a ball	.187	.186	.190	.417	.484	**.566****
Stabilising Foot- Stand on one leg	.266	.336	.364	.343	.276	.178
Mobilising Foot- Smoothing sand	.374	.322	.445	**.572***	**.605***	**.563***
Stabilising Foot- Step up onto a chair	-.065	-.217	.072	.252	.260	.359
Mobilising Foot- Stomp a fast moving bug	.265	.179	.215	.355	.415	.489
Stabilising Foot- Balance on one foot on a railway track	.239	.182	.291	.368	.292	.212
Mobilising Foot- Pick up a marble	.329	.274	.298	.186	.229	.282
Stabilising Foot- Hop on one foot	.434	**.518***	**.656****	.505	.342	.275
Mobilising Foot- Push a shovel into the ground	**.565***	**.558***	**.669****	**.709****	**.705****	**.714****
Stabilising Foot- Weight bearing foot standing	.211	.275	.129	.076	.049	.066
WFQ- Mobilising foot score	.374	.322	.389	.455	**.515***	**.572***
WFQ- Stabilising foot score	.323	.325	.451	.452	.355	.316

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Eight out of fourteen right handed subjects preferred left as their G2 strong side, and six right handed subjects preferred right as their G2 strong side. One subject was left handed, and preferred left as his G2 strong side. Six out of twelve subjects with a right mobilising foot preferred left as their G2 strong side and six preferred right as their G2 strong side. Three subjects with left as their mobilising foot preferred left as their G2 strong side.
Four out of nine subjects with a right stabilising foot preferred right as their G2 strong side, and five preferred left as their G2 strong side. Two out of six subjects with a left stabilising foot preferred right as their G2 strong side, and four preferred left as their G2 strong side.

Table 3. Cross-tabulation of Preferred G2 Strong Side and Laterality

		Handedness		Mobilising foot		Stabilising foot		Total
		Left	Right	Left	Right	Left	Right	
Preferred G2 Strong Side	Left	1	8	3	6	4	5	9
	Right	0	6	0	6	2	4	6
Total		1	14	3	12	6	9	15

The degree of coping with preferred and non-preferred strong side for all intensities was significantly different ($p < 0.05$) in favour of the preferred strong side (Figure 3). Coping with the preferred G2 strong side at the different intensities revealed no significant differences with the Wilcoxon matched-pairs signed-rank test. Coping of the non-preferred side decreased as intensity increased with significant differences between the three highest intensities ($p < 0.05$), but not for the two lowest (Figure 3).

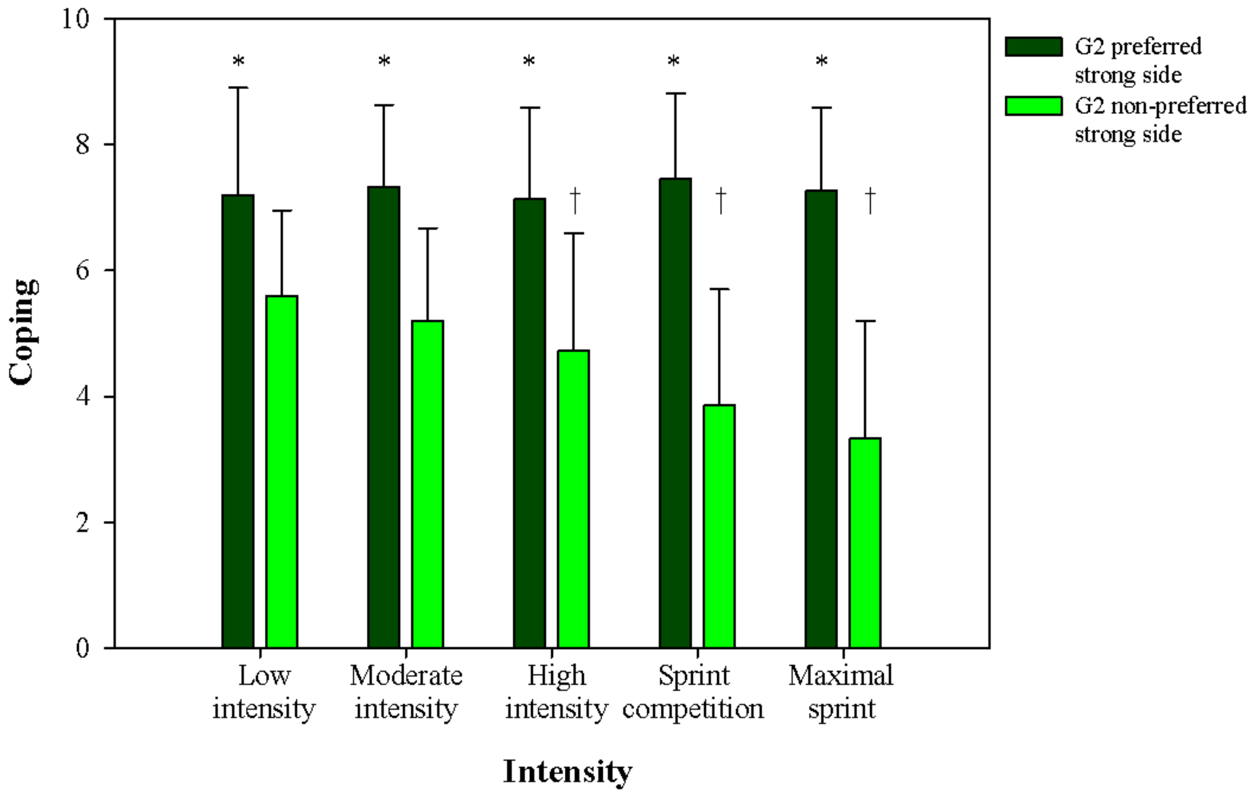

Figure 3. Illustration of how the subjects ranked themselves during different intensities in the G2 technique. * Significantly different to non-preferred strong side. † Significantly different between intensities on non-preferred strong side.

Comparison of strength and power between the preferred G2 strong side and weak side revealed a significant difference ($p < 0.05$) in single leg counter movement jump: rate of force development maximum in favour of the weak side. All other variables were not significantly different ($p > 0.05$) between the preferred G2 strong side and weak side (table 4).

Table 4. Averages of peak power in the upper body and lower body averages of peak force.

	Strong side in G2		**Weak side in G2**		**Sign.**
Variable	Mean	SD	Mean	SD	p
Pull down 10 Kg peak power (W)[a]	3.7	±0.7	3.8	±0.7	-
Pull down 15 Kg peak power (W)[a]	4.2	±0.6	4.3	±0.5	-
Isometric mid-thigh pull clean (N)[b]	12.8	±2.4	12.2	±2.2	-
CMJ height (cm)[c]	21.8	±3.1	21.9	±2.5	-
Peak force CMJ (N)[b]	8.3	±1.6	8.3	±1.6	-
Single leg CMJ RFDmax (N/s)[d]	80.6	±28.5	85.9	±27.2	.041*
Single leg CMJ RFDmean (N/s)[d]	38.9	±19.3	40.2	±16	-
Single leg CMJ Time to peak force (ms)[e]	0.252	±0.1	0.232	±0.01	-
Single leg lateral jump (cm)[c]	185	±17	187	±15	-

[a] =Watt, [b]=Newtons,[c]=Centimeters, [d]=Newtons per second, [e]=milliseconds Peak power, peak force, rate of force development max and mean values are divided on body weight.

4 Discussion

The first objective of this study was to examine if cross-country skiers have a preferred strong side in the G2 ski skating technique, if the preference is related to lateral preference in general, and moreover how is this preference across exercise intensities. The second objective was how athletes' skill of the G2 ski skating technique is influenced by different exercise intensities. Finally we also aimed to elaborate the relationship between preferred strong side in the G2 ski skating technique and muscle strength and power asymmetry.
The main findings were as following: 1) The subjects displayed a preference towards one side in G2 skating, and this preference increased as intensity increased. Lateral preference in the G2 technique was not related to lateral categorization in the Edinburgh Handedness Investigation or the Waterloo Footedness Questionnaire- Revised.2) Cross-country skiers' skill of coping with preferred and non-preferred G2 strong side for all intensities was significantly different in favour of the preferred G2 strong side. The athletes' coping of the preferred strong side remains stable across all intensities, whereas coping of the non-preferred G2 strong side decrease as exercise intensity increase. 3) Comparison of strength and power between the preferred G2 strong side and weak side revealed no significant difference between the preferred G2 strong side and weak side.

Although cross-country skiers lateral preference for the strong side in the G2 technique become greater with increasing intensities, lateral preference in the G2 technique was not related to lateral categorization in the Edinburgh Handedness Investigation or the Waterloo Footedness Questionnaire- Revised. Still, there was a moderate correlation between preferred G2 strong side and some of the WFQ-R tasks and total WFQ-R mobilising foot score. Common for three of the WFQ-R tasks with moderate correlation to the preferred G2 strong ski, was that they all involve the mobilising foot preference. The preferred foot to kick a ball, smoothing sand, push a shovel into the ground, which are mobilising tasks correlated moderately with the preferred G2 strong ski. While the preferred leg to hop on one foot of the stabilising WFQ-R tasks correlated moderately with the preferred G2 strong side. Hart and Gabbard (1997) observed the preferred mobilizing leg in bilateral tasks became the supporting leg in a unipodal balance task for more than half of their subjects. This finding suggesting that the preferred mobilizing leg is somewhat related to the preferred G2 strong side, since the stabilising leg is likely also the mobilizing leg.
The WFQ-R task push a shovel into the ground was the task with the highest correlation with the preferred G2 strong side. This task is also the task in the respective questionnaires involving all limbs, like the G2 technique. The very problem that the handedness and

footedness tests overall score did not correlate with the lateral preference in the G2 technique could be the context of the tasks. The handedness and footedness tests consist of mostly unilateral tasks, while the G2 technique is a whole-body exercise.

This results display that lateral preference of the limbs, can vary through task complexity, and that a sport specific technique, does not correlate well with unilateral motor tasks. Peters (1995) suggested that limb preference causes asymmetry in a certain skill, as a result of increased use of the preferred hand. The G2 technique is perhaps not considered as a fine motor skill. Nonetheless, it is a skilled activity, were proficiency depends on among others strength and coordination. With each limb having a specific role in the G2 technique, following several years of training has led to a modification from the lateral preference categorization in the WFQ-R and Edinburgh Handedness Investigation to this sport specific technique. The tendency in our study is partly in agreement with the findings of Mikheev et al. (2002). They showed that lateral preference is dynamical, were original laterality modificates after extensive sport-specific practice.

Regarding research question two, we found that the degree of coping with preferred and non-preferred strong side for all intensities was significantly different in favour of the preferred G2 strong side (Figure 3). This is in line with previous research within laterality. This finding can relate to our findings in our first research question. Were the subjects displayed a preference towards one side in the G2 technique, and this preference increased as intensity increased. Peters (1995) expressed that lateral preference in a given skill will induce bilateral performance asymmetry as a result of increased use of the preferred limbs with specific roles in a given task. Coping with the preferred G2 strong side in the different exercise intensities revealed no significant differences. Coping of the non-preferred side decreased as intensity increased with significant differences between the three highest intensities but not for the two lowest exercise intensities (Figure 3). In non-preferred G2 strong side skill level changed with skiing exercise intensity, suggesting that exercise intensity is an important factor concerning lateralization in cross-country skiing.

In our third research question, the main finding was that the comparison of muscle strength and power between the preferred G2 strong side and weak side revealed a significant difference only in single leg counter-movement jump: rate of force development maximum in favour of the G2 weak side, all other variables were not significantly different between the preferred G2 strong side and weak side (Table 4).

The findings of significant difference in favour of the preferred G2 weak side single leg counter-movement jump, is in line with Ball et.al (2011), Stöggl (2010) and Babiel (2003). Why it is the preferred G2 weak side leg that has the greatest rate of force development, could be that it is only the G2 weak side leg which is mainly the propulsive limb in its active phase of the G2-skating cycle (Smith, 1992). This corresponds with findings of Stöggl et al. (2010) who reported a higher peak force in weak side ski compared with strong side ski during G2 skating. Babiel (2003) reported higher vertical peak force in favor of the weak ski and slightly higher values for the strong ski in mean vertical force during G2 skating.

However, the single leg counter-movement jump rate of force development maximum was the only variable out of twelve measuring biomechanical bilateral asymmetry that showed any statistical significance. None of the other bilateral strength asymmetry tests showed any significance. If the Isometric mid-thigh pull clean test, with a gradual force generation had revealed a bilateral strength asymmetry in cross-country skiers, then we perhaps could have suggested that the asymmetrical loading pattern in G2 skating would induce strength asymmetries in cross-country skiers. Since bilateral strength asymmetries is less expressed with a gradual force generation (Ball, 2011).

The findings in this study concerning strength and power tests are in contrast to what is found by Newton et al. (2006) who compared dominant and non-dominant leg and addressed strength imbalances among softball players to training one side of the body in sport specific skills. It should be mentioned that Newton et al. (2006) classified strength imbalance by simply compare the leg with highest values against the leg with lowest value, and did not relate strength asymmetries to sport specific lateral preferences.

The degree of asymmetrical loading in the G2 technique (Millet, 1998; Perrey, 1998; Smith, 1992; Street, 1995; Stöggl, 2010) seems not severe enough in this study to impact the athletes` strength symmetry. The usage of one side of the body in the G2 technique is not carried out to the extent that asymmetry may risk injuries (Knapik et al. 1991; Markou, 2006; Yamamoto 1993). This may also be related to the findings in our first research question: how strong is the cross-country skiers lateral preference and how many training hours are spent on the preferred and non-preferred G2 strong side? A second explanation could be the possibility of cross education (Carroll et al. 2008; Stökel & Weigelt 2011).

Conclusion

The current study demonstrates a greater bias towards preferring one side in G2 skating among cross-country skiers, and that this bias increase as intensity increases. The athletes' coping of the preferred strong side remains stable across all intensities, whereas coping of the non-preferred strong side decreases. There were no clear patterns of laterality, strength or power related to the preferences in G2 skating. Thus, lateral preference in the G2 technique is task specific and is not related to laterality in general or the athletes' strength asymmetry.

Methodological implications

Further, there are potential limitations associated with the present study. One methodological limitation of the present study may be that there are no real life observations of the cross-country skiers performing G2 skating technique. However, the subjects were highly skilled cross-country skiers with several hundred training hours yearly. With our method we get their reflection of what they do all of the time, instead of only a short observation in a manipulated experiment. Also, this study has the weakness that the ski-specific questionnaire has not been standardized or validated. Standard, valid, and reliable ski-side questions should be used in future research to increase the understanding of lateralization in sport performance. Perhaps a measure of lateral performance, instead of preference could have been a more suitable measurement of the subjects general lateralization.

The ability to determine asymmetries may also be informative from a coaching perspective, where knowledge of muscle asymmetry and lateral preference may inform the nature of an athlete's training based on performance differences between the two sides of the body.
The practical implications for this investigation of lateral preference in cross-country skiers are that the impact of the asymmetrical loading does not affect the athletes' strength symmetry. Moreover, the injury risk is not increased by the asymmetrical loading in the movement pattern in the G2 technique.

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