Sollie, O., Holmsen, K. E., Steinbo, C. K., Ommundsen, Y., Losnegard, T. J. (2021). Observational vs coaching feedback on non-dominant whole-body motor skill performance — application to technique training. *Scandinavian Journal of Medicine & Science in Sports, 31*(11), 2103-2114. http://dx.doi.org/10.1111/sms.14030

Title

Observational vs coaching feedback on non-dominant whole-body motor skill performance – application to technique training

Authors:

Ove Sollie [1,] Kristian Holmsen [1], Christian Steinbo [2], Yngvar Ommundsen [2], Thomas Losnegard [1]

[1] Department of Physical Performance, Norwegian School of Sports Sciences, Oslo, Norway

[2] Department of Sport and Social Sciences, Norwegian School of Sports Sciences, Oslo, Norway

Address for correspondence:

Ove Sollie

Department of Physical Performance,

Norwegian School of Sport Sciences,

Sognsveien 220,

PO Box 4014 Ullevål Stadion,

0806 Oslo, Norway

e-mail: ove.sollie@nih.no

Acknowledgments

The authors thank Magne Lund Hansen for his contribution during the intervention and Ola Eriksrud for valuable input to the manuscript.

Abstract

We studied the effect of peer- and self-observational feedback versus coaching feedback during technique training on performance in competitive adolescent cross-country skiers. Fifty-four skiers (14.3±0.6 years) were divided into a control group and three intervention groups (dyad practice, video or coaching feedback), which practiced in the asymmetrical uphill sub-technique G2 on one side (non-dominant side), but not the other (dominant side) for 6x30 min over a 5-week period, on rollerskis outdoors. High-speed performance and skiing economy were assessed on a rollerski treadmill before and after the intervention, and a questionnaire was answered post-intervention. The video feedback (P=.025, d=.65) and coaching feedback (P=.007, d=.89) groups improved high-speed performance during the intervention and an ANCOVA showed a tendency for different change scores between interventions ($F_{3,49}$ = 2.5, P = .068, η_p^2 = .134), with a difference between the coaching feedback and dyad practice (P=.05). No change was seen in skiing economy in any group. Coaching feedback ranked higher on enjoyment compared to dyad practice (P<.001) and led to higher self-perception of improved technique compared to the control group (P=.038). Overall, feedback from a competent coach seems better than observation for improving performance in young athletes, although self-observation through video with attentional cues seems a promising tool for increasing individual feedback when coaching large groups.

Key Words: motor learning, video feedback, dyad practice, talent development, motor performance, practice efficiency

1 Introduction

Athletic development is multifaceted and is based on a complementary mix of athletic attributes and skills to be acquired and improved [1]. One of the pillars of endurance performance is the ability to transform metabolic energy efficiently into speed [2,3]. This is coupled with an "efficient technique", which can be defined as "the relative position and orientation of body segments as they change during the performance of a sport task to perform that task effectively" [4]. Although key identifiers of such efficient sport-specific techniques have been widely studied [4], less is known about how these are acquired in an applied practice setting.

Technique training in applied settings aims to implement deliberate practice, which facilitates beneficial technique modifications and results in a more efficient technique and improved performance. In applied youth sport practice settings, this most often occurs in groups with a high athlete-to-coach ratio, which restricts coaches' opportunities to provide individual feedback [5]. Thus, organizing practice sessions to facilitate more individual feedback is an important aspect of technique training. However, previous research has been based on interaction with a single participant at a time [5] and few ecologically valid feedback studies from applied sport practice settings exist [6].

Augmented feedback is one of the most important features for acquiring and improving sport-specific technique [7]. In applied sport practice settings, the coach often provides augmented feedback to facilitate the process of acquiring a more efficient technique. However, a coach does not necessarily provide feedback that facilitates this process optimally [8]. Furthermore, in youth sports, the coach is often a non-professional, such as a parent or other volunteer with limited content knowledge both of efficient sport-specific technique and of how to effectively promote this technique.

Observation of others, or oneself, is frequently used to assist athletes' learning processes in applied sport practice settings [9] and may enhance learning [6,10] as well as increasing learners' motivation [11]. Two observational methods promoting more individual feedback are peer-model observation through dyad practice, where two athletes interactively observe and instruct each other, and conducting self-observation through video [6,11]. Dyad practice may increase cognitive involvement [11], as well as ownership of and responsibility for the learning process, and consequently improve motor learning [12]. Today's smartphones, with large high-resolution screens, may provide practice settings where multiple individuals receive immediate viewable feedback simultaneously [5] with positive performance outcomes [13]. However, the results from using video feedback for performance outcomes have been equivocal [6], implying the need to reduce the information given to young athletes. Therefore, video feedback with attentional cues, where the athlete's attention is directed to the most appropriate aspects of the technique, can accelerate the process of beneficial technique modification [14,15], and has been shown to be superior to video feedback only [16]. Both verbal and visual cuing have been shown to facilitate the acquisition of efficient technique [17]. However, in applied sport practice settings with a high athlete-to-coach ratio, feedback methods with cueing promoting more individual feedback should be explored. As such, written cue cards may give attentional cues to multiple athletes simultaneously in applied sport settings.

The movement pattern in cross-country (XC) skiing consists of a complex interaction between upper and lower body where movement patterns are categorized into different sub-techniques. In the asymmetrical uphill sub-technique G2, skiers have a dominant and a non-dominant side. This technique is therefore well suited to assess the effect of different feedback methods and assessing improvement in technical execution for complex movement patterns since within-individual comparisons can be made, as skiers can practice the non-dominant side while the dominant side acts as a control for physiological responses. In this way we can distinguish between technical and physiological changes during an intervention. In sports, deliberate technique practice needs to facilitate increased performance (or fewer injuries) to have relevance for the athlete. We therefore compared two observational feedback methods with feedback from a competent coach on performance changes on the non-dominant side in the XC-skiing G2 skating technique, where all groups used cue cards to control the content of feedback information.

2 Material and methods

2.1 Participants

Fifty-four adolescent competitive XC-skiers participated in the study (Table 1). The athletes were recruited from four local XC-ski clubs. Inclusion criteria were 1) attending local club training regularly; 2) participating in regional and/or national XC-skiing competitions; 3) experience with rollerskiing; and 4) for intervention groups, attending five of six practice sessions (6/6: 24 participants, 5/6: 17 participants). Participants and their parents were informed of the nature of the study and the possible risks involved before giving their written consent. The study was approved by the Human Research Ethics Committee of The Norwegian School of Sport Sciences and registered with the Norwegian Centre for Research Data.

<<Table 1 near here>>

2.2 The G2 skating sub-technique.

Competitive XC-skiing consists of two main techniques (classic and skating) each with several sub-techniques. The choice of sub-technique depends mainly on speed and therefore act as a "gearing system" [18]. The uphill skating sub-technique Gear 2 (G2, also called V1 or "paddling") is characterized by asymmetrical double poling action during leg push-off on the "strong side", but not on the "weak side" (Fig. 1). Most skiers have a preferred "strong side" either to the left or right side of the body (dominant side) and changing the "strong side" to the other side of the body (non-dominant side) is used less and usually with less efficient technique [19,20]. In the present study, all participants had a clear-cut opinion of which side was dominant and which was non-dominant (30 and 24 athletes with the dominant side to the right and left respectively).

<<Figure 1 near here>>

2.3 Apparatus

A detailed description of the apparatus used in the present study can be found in Losnegard et al. (2012) [21]. Testing procedures and apparatus used were identical pre- and post-intervention tests. All testing was performed on a rollerski treadmill and identical roller skis and poles were used pre- and post-intervention. The athletes used their own equipment during the intervention training sessions. No technique instruction was given during laboratory testing. All tests were performed using the G2 technique.

2.4 Experimental overview

The athletes performed two familiarization sessions before the main test session pre-intervention (Fig 2, upper panel). During the five-week intervention period the athletes performed 6x ~30 min practice sessions on rollerskis using the G2 technique on the non-dominant side, before a new main test session post-intervention. The performance testing pre- and post-intervention was performed on a rollerski treadmill and performance outcomes were the change scores from the pre- to post-intervention in maximal relative power output from an incremental speed test and skiing economy during sub-maximal rollerskiing. The athletes were divided into a control group and three intervention groups. The feedback methods during the intervention were Dyad practice (DYAD), Video feedback (VIDEO), and Feedback from an expert coach (COACH). The control group (CON) performed only the main test sessions pre- and post-intervention, with no intervention practice sessions in between. The intervention groups used identical attentional cue cards to control the content of feedback information. The timing, frequency and amount of feedback were identical between groups (Table 2).

<<Figure 2 near here>>

2.5 Testing

Familiarization: The skiers completed two familiarization sessions in which they became thoroughly accustomed to the treadmill and the different tests using the same apparatus that would be used during the main test sessions. All participants followed the same familiarization protocol. The first familiarization consisted of 30 min of submaximal roller-ski skating before completing two incremental speed tests (see later). The second familiarization session consisted of a 10-min easy self-paced warm-up and two 5-min sub-maximal G2 efforts with cardiorespiratory measurements for familiarization with the equipment.

Time-trial: At the end of the second familiarization day, a 3-min time-trial (TT_{3min}) was performed to assess cardiorespiratory variables and performance ($\dot{V}O_{2peak}$ and distance). TT_{3min} started on an 8° incline and 2.25 $m \cdot s^{-1}$ for the boys and 2.0 $m \cdot s^{-1}$ for the girls. This speed was fixed during the first 30 s to prevent the participants from starting too fast. Thereafter, the test was performed paralleling procedures as the sprint test reported in Losnegard et al. (2012) [21]. The test was performed twice, once on the dominant side and once on the non-dominant side, in a randomized order, separated by a 10 min break.

2.5.1 Main test session

An overview of the testing session is illustrated in Fig. 2, bottom panel. Before the pre-intervention test session, the order of dominant vs. non-dominant side was randomized and the participants used the two different sides every other time for the different work bouts throughout the test session. The participants followed the same order during the post-intervention test session.

Submaximal workloads: An easy self-paced 6-min warm up, 3 min on the dominant and 3 min on the non-dominant side, was completed using the G2 technique before four 5-min sub-maximal work bouts. The results from the first two 5-min steady-state stages are not discussed in this paper. Thereafter, the subjects completed two further 5-min efforts at a pace corresponding to the same estimated relative intensity (~83% of $\dot{V}O_{2peak}$, 6° incline). Cardiorespiratory variables and heart rate were monitored from 2-5 min and the averages for 2.5-5 min provided the steady state values used for further analysis. Each 5-min bout was separated by a 2-min break.

Incremental speed test: The speed test was performed 10 min after the last sub-maximal work bout on both dominant and non-dominant sides, separated by a 10-min break. The incline was set to 8°, with a starting speed of 2.5 m/s (estimated O2-cost of ~66 $ml \cdot kg^{-1} \cdot min^{-1}$). The speed then increased automatically by 0.25 m/s every 15 s (estimated increase of ~7 $ml \cdot kg^{-1} \cdot min^{-1}$). Thereafter, the athletes adjusted their position on the treadmill as in TT_{3min}. The test was terminated manually by the test leader when the skiers could not keep the front wheels of their rollerskis in front of a laser beam projected on to the treadmill behind the skiers for two consecutive cycles. HR was measured throughout the test. W_{max} from the speed test was determined as:

W_{max} = Workload for the last step completed + [(Increase in workload for each step/duration of each step) x duration of final step].

2.6 Feedback intervention

All groups performed the intervention at the same time of the season (September-October). The four XC-skiing clubs were randomly assigned to an intervention group or to the control group, and no club had skiers in more than one group. The number of boys and girls in each group was given by the skiers volunteering for the study from each XC-skiing club.

2.6.1 Practice sessions

Each intervention practice session lasted ~30 min and was designed so the groups had the same timing, frequency and amount of practice time (3x5 min) and feedback time (2x5 min) during each session. The practice was only performed on the participants' non-dominant side. All groups used the same written cue cards to control the feedback information given and to guide the attention of the athletes to the session focus and corresponding appropriate movements (Table 2). The athletes were observed/filmed from the front in all intervention groups. In four of the training sessions, the athletes worked on specific tasks/questions, while in two of the training sessions (sessions 3 and 6) the questions were more open (Table 2). The list was designed combining findings from previous research on the G2 technique [22] with the experience of professional XC-skiing coaches. All groups practiced at low intensity, competition speed and sprints for each of the three types of sessions.

<<Table 2 near here>>

2.6.2 Groups

Dyad practice (DYAD): The skiers (10 boys, 3 girls) formed pairs and observed each other and gave feedback on two runs for each of the two feedback periods. In training sessions with uneven number of skiers, one group of three skiers worked together with two observers to each practicing skiers. The observer gave feedback to the practicing athlete immediately after each run based on the cue cards. The skiers receiving the feedback were encouraged to ask questions and discuss the feedback. The partners were the same throughout each session but changed between sessions.

Video feedback (VIDEO): The skiers (5 boys, 10 girls) formed pairs and filmed each other with their own smartphones for two runs each of the two feedback periods. In training sessions with uneven number of skiers, a group of three skiers worked together. The rest of the feedback period was used to evaluate the videos of themselves using the cue cards before they practiced based on the cues they got from studying the video. No other instruction was given to the participants.

Coaching feedback (COACH): The skiers (7 boys, 6 girls) were separated in to three smaller groups, each trained by an experienced XC-skiing coach (all with 10+ years of experience). The three coaches were the same throughout the intervention. The coaches used the same attentional cue cards for feedback as the other groups. Further, the coaches gave coaching cues that were evidence-based, with an external focus of attention and an autonomy-supportive instructional language to facilitate learning [23,24]. The athletes followed a rotational system such that none of the groups were the same for more than one training session and the athletes were coached by the same coach twice during the intervention. Further, before each practice session the coaches agreed on the feedback information given for each of the attentional cues and for the different variations of technical execution that could occur. The participants received feedback after two runs in each of the two feedback periods. The participants knew the focus of the session cue cards, and they were always asked their own opinion regarding their technical execution in relation to the attentional cues/questions before receiving feedback from the coach.

Control group (CON): The skiers (5 boys, 8 girls) did not attend any intervention practice session but continued with their normal training regime. They were not instructed or given any information with respect to whether they should practice the non-dominant side or not.

They followed the same test procedures with the same time period between tests as the intervention groups.

2.7 Questionnaire

After the post-intervention tests, the intervention groups self-reported on three items, while the control group answered only the last two of these items. Items one and two were reported on a 5-point Likert scale. The third question was a self-report on how many times they had practiced on their non-dominant side on their own during the intervention period (Table 3).

<<Table 3 near here>>

2.8 Statistics

Raw data are presented as mean ± standard deviation (SD) unless otherwise stated. Normality of the data was assessed using the Shapiro-Wilks test of normality (α=0.05). Outliers were assessed by inspection of boxplots and by examination of studentized residuals for values greater than ±3 (one athlete was removed from the speed test on the dominant side in VIDEO with a value of -3.27). For statistical tests, the level of confidence was set to 95% and a level of $P \leq 0.05$ was considered significant, while $P \leq 0.1$ was considered as a tendency. Relative differences between pre- and post-intervention tests and relative differences between the non-dominant and dominant side are presented as mean ± 95% confidence interval (CI). Changes in W_{max} and $\dot{V}O_2$ from the sub-maximal workload from pre- to post-intervention were determined using a two-tailed paired Student's t-test. To detect differences between groups during the intervention, one-way ANCOVA was run on the change scores (Post-Pre) on relative W_{max} from the speed test and $\dot{V}O_2$ and heart rate during the sub-maximal workloads, to control for pre-intervention scores. The typical error (expressed as CV%) for the speed test was 2.7% (calculated from the familiarization test and the pre-intervention test). We were not able to calculate the typical error for $\dot{V}O_2$ during the submaximal workload for these athletes, but the typical error for elite athletes is 1.2% [25]. Partial eta squared effect sizes (η_p^2) were reported for ANCOVA tests where 0.14 or more, 0.06 or more and 0.01 or more were considered large, medium and small effects, respectively [26]. Bonferroni corrections for multiple comparison were applied for all ANCOVA and ANOVA tests. The magnitudes of differences between groups and the relative difference between dominant and non-dominant sides were expressed as standardized mean differences (Cohen's *d* effect size - d < 0.2 considered to be a very small, 0.2-0.5 a small, 0.5-0.8 a medium and d > 0.8 a large effect) [26]. A Kruskal-Wallis H test was run to determine whether differences were present between groups for items one and two in the questionnaire. Distributions of each item were assessed by visual inspection of a boxplot. Distributions for the items were not similar between groups. Therefore, we compared mean ranks. Pairwise comparisons were performed using Dunn's (1964) procedures with a Bonferroni correction for multiple comparisons [27]. Adjusted *P* – values are presented and values in parentheses are mean ranks. A one-way ANOVA was performed on item 3.

3 Results

Differences between dominant and non-dominant sides for the athletes' pre-intervention test scores are shown in Table 4.

<<Table 4 near here>>

3.1 Speed test (W_{max})

Within-group effects: There was an improvement in high-speed performance (increased time to task failure) (mean ± 95% CI) between pre- and post-intervention tests on the non-dominant side for VIDEO (2.1 ± 1.8 %) and COACH (3.8 ± 2.4 %) and a tendency for CON (1.7 ± 1.9 %), with no effect for DYAD (-0.2 ±1.6 %). There was no change in performance for the dominant side in any group (Table 5).

<<Table 5 near here>>

Between-groups effect: There was a tendency to a difference in change scores for the non-dominant side between interventions ($F_{3,49}$ = 2.5, *P* = .068, η_p^2 = .134), with a significant difference between COACH and DYAD (*P* = 0.05, diff. of 4.0 % , 1.2 to 6.7 %, *d* = 1.18, large effect) (Fig. 3, upper right panel). No difference was found between any of the groups for the dominant side ($F_{3,49}$ = 0.6, *P* = .608, η_p^2 = .036).

<<Figure 3 near here>>

3.2 Submaximal Workloads

Within-group effects: There was no difference between pre- and post-intervention tests for skiing economy ($\dot{V}O_2$) or HR (*P* = .11 to .97 and Cohens *d* = .48 to .01) on the non-dominant or the dominant side.

Between-groups effect: No difference in change scores between groups was found for skiing economy ($\dot{V}O_2$) ($F_{3,49}$ = .67, *P* = .58, η_p^2 = .039) (Fig. 3, bottom panels) or HR ($F_{3,49}$ = .76, *P* = .52, η_p^2 = .045) on the non-dominant side or the dominant side.

3.3 Practice

After the post-intervention tests, the athletes answered a questionnaire that used three items (Table 3).

Item 1 (Enjoyment): The mean ranks of scores were different between the three intervention groups, $\chi^2(2) = 16.859$, $P < .001$) showing that COACH (29.96) scored better compared to DYAD (12.35) ($P < .001$) and there was a tendency toward better scores for COACH compared to VIDEO (20.73) ($P = .078$).

Item 2 (Self-perception of improved technique): The mean ranks of scores were different between the groups ($\chi^2(3) = 8.857$, $P = .031$) showing that COACH (32.73) scored better compared to CON (17.58) ($P = .038$).

Item 3 (Number of self-practice): A difference between groups was found for number of self-practices during the intervention for the G2 non-dominant side technique ($F_{3.53} = 8.2$, $P < .001$) where COACH practiced more compared to CON ($P < .001$ mean diff. of 5.4% (95% CI 2.4 to 8.5%) and VIDEO ($P = .03$, mean diff. of 3.1% (95% CI 0.2 to 6.0%) and there was a tendency that DYAD practiced more compared to CON ($P = .054$, mean diff. of 3.0% (95% CI 0.0 to 6.0%). The number of self-practices did not correlate with changes in performance ($r < 0.1$).

4 Discussion

The aim of the present study was to investigate the effect of observational feedback, providing more individual feedback in groups with a high athlete-to-coach ratio, compared to coaching feedback on performance. We used a novel approach with a long-duration intervention in an applied setting, providing the possibility to investigate intra-individual changes in performance between dominant and-non-dominant sides. Our main finding was that high-speed performance improved in COACH and VIDEO from pre- to post-intervention, and that performance improved more in COACH compared to DYAD. Moreover, COACH ranked higher on enjoyment compared to DYAD and led to higher self-perception of improved technique compared to CON.

To prevent the amount of feedback being different between groups and potentially affecting the results, COACH had three coaches for each session to maintain similar timing, frequency and cueing between groups. COACH was the only group to reach a large effect size ($d = .89$) for high-speed performance from pre- to post-intervention and the athletes ranked COACH high on enjoyment. This may imply that coaches can satisfy fundamental psychological needs found to be important, such as enhanced expectancies and positive affect, which may influence learning and performance outcomes in athletes [24]. In addition, COACH showed more self-practice during the intervention compared to CON and VIDEO. More self-practice on the non-dominant G2 technique did not correlate with performance improvement during the intervention, so the improvement in COACH was due to the feedback method and not the amount of self-practice. However, more self-practice over a longer training period might reflect intrinsically regulated motivation for practice [24], which has been found to positively influence performance in the long run [28]. Therefore, having a low athlete-to-coach ratio in applied group practice settings seems like a good approach for technique training if practically possible. However, applied youth sport practice settings usually do not have this luxury and furthermore, the coaches may be non-professionals. Therefore, organizing practice sessions where more athletes receive feedback that facilitates beneficial technique modifications can be considered a critical element in the development of efficient technique for youth athletes.

Using the athletes' own smart phones and interactive dyad practice can increase individual feedback in groups with a high athlete-to-coach ratio, but feedback methods need to facilitate beneficial technique modification to have relevance for the athlete. Of the two observational feedback methods, only VIDEO improved high-speed performance during the intervention ($P = .025$, $d = .65$) and the change score adjusted for pre-intervention scores was not different from COACH. VIDEO received no coaching feedback, and obviously, more individual feedback was received per coach compared to COACH, with similar changes in performance. The effect of video feedback on technique improvements has been equivocal [6], but in the present study the attentional cue cards may have helped the athletes to direct their attention to relevant aspects of the technique [15]. Although the change scores between VIDEO and DYAD were not different, only VIDEO improved the high-speed performance from pre- to post-intervention. Athletes' self-observation may be a more powerful tool than observation of others because the self-generated video action is more informative to the athlete due to heightened similarity [29]. Video feedback using athletes' own smart phones with attentional cue cards may therefore serve as a complementary tool for coaches providing technique feedback in large groups.

We included a control group to investigate whether the intervention groups improved more than skiers who did not undertake deliberate practice on the non-dominant side. Although only VIDEO and COACH increased high-speed performance from pre- to post-intervention, CON showed a tendency for increased high-speed performance (P = .077, d = .54) and there was no difference between COACH, VIDEO and CON for pre-intervention adjusted change scores. However, CON ranked low on self-perceived technique improvement and this group did not practice the non-dominant G2 technique during the intervention period. Further, control groups in motor learning studies might not be completely "neutral" [24]. In this regard, some skiers in CON reported that they were very motivated to perform better on the post test, even though they did not know the results from the first test. The fact that they were part of an experimental study might therefore have affected the results. Furthermore, there were large inter-individual differences in the physiological responses in the different groups (Fig. 3). This may suggest that individual preferences for feedback exist and should be taken into consideration when coaching groups of athletes. Thus, as a coach, one might potentially degrade the level of technique in some athletes if one is not paying attention to individual needs.

A somewhat surprising finding was that DYAD did not improve performance. Although dialogues in the present study were not recorded or formally analyzed, informal observations from DYAD indicated that the athletes often focused on non-relevant movements and gave feedback with an internal focus of attention. It has been repeatedly shown that an external focus of attention facilitates learning [23] and the athletes may have adopted a higher self-focus and thus became overly aware of their movements, which may have reduced motor learning [24]. Participants in collaborative or cooperative learning situations often anecdotally report more enjoyment than they have experienced when learning alone [30]. However, this was not expressed in the present study, where DYAD ranked low on enjoyment. Many of the athletes commented that they thought it was difficult to coach other athletes even though they had the attentional cue cards. VIDEO did not express this view when "coaching" themselves. The athletes' preexisting knowledge of the movement was perhaps too limited to understand how to best instruct another athlete [28] and dyad practice in this case may have been a method better suited for more experienced athletes with higher sport-specific technique content knowledge. Nevertheless, dyad practice has previously been shown to increase participants' feeling of responsibility for and involvement in the learning process, meaning that they were prepared to invest more cognitive effort and to engage in processing activities that they would not have engaged in otherwise [11]. Furthermore, previous research suggests that dyad practice may result in more flexible or generalisable capability [23], which may facilitate the development of technique in sports consisting of complex movements like XC-skiing. However, in our case the intervention period may have been too short and the preexisting sport-specific technique knowledge of the athletes too limited to be able to verify the potential benefits of such dyadic practice.

As expected, skiing economy on the non-dominant side was less efficient than the dominant side during the pre-intervention test (n=54, Table 4). The ability to efficiently transform metabolic energy into speed is important for XC-skiing performance [3,31] and previous studies have shown that beneficial technique modifications in XC-skiing improve skiing economy and performance [25,32]. An improved skiing economy in the present study is therefore expected to come from beneficial technique modification and thereby improve XC-skiing performance. However, no change was found in skiing economy during submaximal efforts during the intervention in any of the groups. Our intervention period might have been too short as changing skiing economy with technique modifications may take longer to develop in adolescent skiers [33,34]. Further, exercise intensity is an important factor in terms of how skiers cope with the G2 non-dominant technique in cross-country skiing, which skiers find more challenging at higher intensities [20]. This was also evident in the present study as the magnitude of the difference between sides increased as the speed increased (Table 4).

4.1 Methodological considerations

The most effective movement pattern is not identical between XC-skiers and therefore technique modifications need to facilitate increased performance (or fewer injuries) to have relevance for the athlete. Therefore, performance changes should be monitored in studies on motor learning for athletes. However, although the performance of young athletes improves, this does not necessary imply that learning or beneficial technique modification have occurred, because the physical capacity of young athletes develops rapidly.

A strength of the present study is that we were able to control for this when simultaneously testing the dominant side of the G2 technique. As there was no improvement on the dominant side, we propose that changes on the non-dominant side were due to improved technique and not just a change in physical capacity. However, in the present study, we assessed only knowledge-of-result; i.e. the performance effects of the interventions. Future studies should assess the knowledge-of-performance; i.e. using kinematical measures to detect whether the athletes changed their technical execution in response to the cues given during the intervention period.

In an applied practice setting it was difficult to control the information the athletes gave each other in DYAD, or the thoughts of the athletes in VIDEO. There were three researchers involved in every training session in VIDEO and DYAD to control the practice setting, but the observations and dialogues were not recorded or formally analyzed in these groups. Even though all intervention groups used the same cue cards, the information received and the interpretation of this information by the athletes might therefore be different. Further, it could well be that the skiers were influenced by the coaching methods of their ordinary coaches in their skiing clubs.

A limitation of the present study is that testing was conducted in the laboratory, while the athletes performed the practice sessions outside on asphalt. It was not practically possible to train all athletes indoor due to the high number of athletes involved. Besides, doing so would have reduced ecological validity. Moreover, the data collection for cardiorespiratory and kinematic data (data not shown) required indoor testing. However, the athletes were familiarized with the treadmill, as seen in the absence of difference in performance from the last familiarization session to the pre-intervention main test session for the speed test (difference of 0.1 ± 1.1%). Further, rolling resistance has been found to be similar for treadmills and asphalt [35], and should not have affected the results in the present study.

We did not have a retention test, due to the advanced time-consuming performance tests and the large number of athletes. However, most of the athletes performed the post-testing session several days after the last practice session and the time from the last practice session to post-intervention test was balanced between groups. Further, a continuous motor skill task like the G2 technique is very well retained over long time intervals [36].

We only asked the athletes one question relating to enjoyment and one question on self-perception of improved technique. Our questions may therefore have reduced validity and should be interpreted with caution.

5 Perspectives

When timing, frequency and amount of feedback are similar, coaching feedback from a competent coach seems superior in terms of combined performance, perceived enjoyment, self-perception of improved technique, and amount of self-practice performed compared to video feedback and dyad practice. However, video feedback with cue cards, filmed on the athletes' own smart phones, could be a valuable tool for coaches who want to increase individual feedback when coaching large groups or when the coach's sport-specific technique knowledge is limited. A combination of these feedback methods might be a good strategy. For dyad practice, the intervention period may have been too short and the preexisting sport-specific technique knowledge of the athletes too limited to be able to verify the potential benefits of this method. There was a large inter-individual variation in each group, and some athletes in each group were negatively affected. It should therefore be acknowledged that there might be individual preferences that should be taken into consideration when giving feedback, and as a coach, one might potentially degrade the level of technique in some athletes if attention is not paid to individual needs.

References

1. Bergeron MF, Mountjoy M, Armstrong N, et al. International Olympic Committee consensus statement on youth athletic development. *Br J Sports Med.* 2015;49(13):843-851.
2. Saunders PU, Pyne DB, Telford RD, Hawley JA. Factors affecting running economy in trained distance runners. *Sports Med.* 2004;34(7):465-485.
3. Losnegard T, Myklebust H, Spencer M, Hallen J. Seasonal variations in VO_{2max}, O_2-cost, O_2-deficit, and performance in elite cross-country skiers. *J Strength Cond Res.* 2013;27(7):1780-1790.
4. Lees A. Technique analysis in sports: a critical review. *J Sports Sci.* 2002;20(10):813-828.
5. Van der Kamp J, Duivenvoorden J, Kok M, van Hilvoorde I. Motor skill learning in groups: Some proposals for applying implicit learning and self-controlled feedback. *RICYDE Revista Internacional de Ciencias del Deporte.* 2015;11(39):33-47.
6. Ste-Marie DM, Law B, Rymal AM, Jenny O, Hall C, McCullagh P. Observation interventions for motor skill learning and performance: an applied model for the use of observation. *Int Rev Sport Exerc Psychol.* 2012;5(2):145-176.
7. Magill R, Anderson D. Motor learning and control: concepts and applications. 2011. In: New York: McGraw-Hill Higher Education.
8. Porter JM, Wu W, Partridge JA. Focus of attention and verbal instructions: Strategies of elite track and field coaches and athletes. *Sport Sci Rev.* 2010;19(3-4):199-211.
9. Cumming J, Clark SE, Ste-Marie DM, McCullagh P, Hall C. The functions of observational learning questionnaire (FOLQ). *Psychol Sport Exerc.* 2005;6(5):517-537.
10. Shea CH, Wright DL, Wulf G, Whitacre C. Physical and observational practice afford unique learning opportunities. *J Mot Behav.* 2000;32(1):27-36.
11. Shea CH, Wulf G, Whitacre C. Enhancing Training Efficiency and Effectiveness Through the Use of Dyad Training. *J Mot Behav.* 1999;31(2):119-125.
12. Lee TD, Swinnen SP, Serrien DJ. Cognitive Effort and Motor Learning. *Quest.* 1994;46(3):328-344.
13. Nowels RG, Hewit JK. Improved Learning in Physical Education through Immediate Video Feedback. *Strategies.* 2018;31(6):5-9.
14. Williams AM, Davids K, Williams JG. *Visual perception and action in sport.* New York: E & FN Spon; 1999.
15. D'Innocenzo G, Gonzalez CC, Williams AM, Bishop DT. Looking to Learn: The Effects of Visual Guidance on Observational Learning of the Golf Swing. *Plos One.* 2016;11(5):e0155442.
16. Kernodle MW, Carlton LG. Information feedback and the learning multiple-degree-of-freedom activities. *J Mot Behav.* 1992;24(2):187-196.
17. Janelle CM, Champenoy JD, Coombes SA, Mousseau MB. Mechanisms of attentional cueing during observational learning to facilitate motor skill acquisition. *J Sports Sci.* 2003;21(10):825-838.

18. Nilsson J, Tveit P, Eikrehagen O. Effects of speed on temporal patterns in classical style and freestyle cross-country skiing. *Sports Biomech.* 2004;3(1):85-107.
19. Stoggl T, Hebert-Losier K, Holmberg HC. Do anthropometrics, biomechanics, and laterality explain V1 side preference in skiers? *Med Sci Sports Exerc.* 2013;45(8):1569-1576.
20. Thorrud S. Is laterality, intensity or strength asymmetry associated with the preferred side in the G2 skating technique in cross-country skiing? 2013.
21. Losnegard T, Myklebust H, Hallen J. Anaerobic capacity as a determinant of performance in sprint skiing. *Med Sci Sports Exerc.* 2012;44(4):673-681.
22. Stoggl T, Holmberg HC. Three-dimensional Force and Kinematic Interactions in V1 Skating at High Speeds. *Med Sci Sports Exerc.* 2015;47(6):1232-1242.
23. Wulf G, Shea C, Lewthwaite R. Motor skill learning and performance: a review of influential factors. *Med Educ.* 2010;44(1):75-84.
24. Wulf G, Lewthwaite R. Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychon Bull Rev.* 2016;23(5):1382-1414.
25. Losnegard T, Tosterud OK, Troen E, Carlsen CH, Paulsen G, Rud B. The influence of pole lengths on O2-cost, kinematics, and performance in double poling at high speeds before and after a training period with long poles. *Eur J Appl Physiol.* 2019;119(11-12):2579-2587.
26. Cohen J. Statistical power analysis for the social sciences. 1988.
27. Dunn OJ. Multiple comparisons using rank sums. *Technometrics.* 1964;6(3):241-252.
28. Ericsson KA, Krampe RT, Teschromer C. The Role of Deliberate Practice in the Acquisition of Expert Performance. *Psychol Rev.* 1993;100(3):363-406.
29. Knoblich G, Flach R. Predicting the effects of actions: interactions of perception and action. *Psychol Sci.* 2001;12(6):467-472.
30. Mueller D, Georges A, Vaslow D. Cooperative learning as applied to resident instruction in radiology reporting. *Acad Radiol.* 2007;14(12):1577-1583.
31. Sandbakk O, Holmberg HC, Leirdal S, Ettema G. Metabolic rate and gross efficiency at high work rates in world class and national level sprint skiers. *Eur J Appl Physiol.* 2010;109(3):473-481.
32. Losnegard T, Myklebust H, Ehrhardt A, Hallen J. Kinematical analysis of the V2 ski skating technique: A longitudinal study. *J Sports Sci.* 2017;35(12):1219-1227.
33. Zoppirolli C, Modena R, Fornasiero A, et al. Talent development in young cross-country skiers: longitudinal analysis of anthropometric and physiological characteristics. *Frontiers in Sports and Active Living.* 2020;2:111.
34. Skattebo O, Hallen J, Ronnestad BR, Losnegard T. Upper body heavy strength training does not affect performance in junior female cross-country skiers. *Scand J Med Sci Sports.* 2016;26(9):1007-1016.
35. Gloersen O, Losnegard T, Malthe-Sorenssen A, Dysthe DK, Gilgien M. Propulsive Power in Cross-Country Skiing: Application and Limitations of a Novel Wearable Sensor-Based Method During Roller Skiing. *Front Physiol.* 2018;9:1631.
36. Schmidt RA, Lee TD, Winstein C, Wulf G, Zelaznik HN. *Motor control and learning: A behavioral emphasis.* Human kinetics; 2018.

Tables

Table 1.

Characteristics of the skiers at pre-intervention test

	Boys (n=27)	**Girls (n=27)**
Age (years)	14.2±0.6	14.3±0.6
Body mass (kg)	57.2±7.7	55.9±8.1
Body height (cm)	172.1±7.4	166.8±4.9
Rollerski G2 VO_{2peak} ($ml \cdot kg^{-1} \cdot min^{-1}$)	61.9±5.6	53.5±5.8
Weekly training (h)*	9.3±3.6	8.6±3.2

Data is reported as mean ± standard deviation. *Weekly training was self-reported, VO_{2peak} was measured on the dominant side in the G2 skating technique

Table 2

An overview of the attentional cues/questions from each session. The questions are translated from Norwegian.

Session focus	**Session number**	**Attentional cues/questions**	
Rhythm	1 and 4	Main question	What do you think about the rhythm?
		Secondary questions	• Do two poles and one ski hit the ground at the same time? • Are the movements “smooth and flowing” or are they “jagged”?
Sideways weight transfer	2 and 5	Main question	What do you think about the weight transfer from ski to ski?
		Secondary questions	• Does the upper body follow the same direction as the skis? • Do you push with both poles and skis actively?
Overall technique	3 and 6	Questions	• What is good about your technique? • What can be improved about your technique?

Table 3

Questionnaire the athletes answered after post testing. The questions are translated from Norwegian.

Item 1	**How much did you like the intervention feedback method?**				
	Very unsatisfied	Unsatisfied	Neutral	Satisfied	Very satisfied
Item 2	**Have you improved your technique on your non-dominant side?**				
	Very unlikely	Unlikely	Neutral	Likely	Very Likely
Item 3	**How many times have you trained on the non-dominant side on your own**				

	during the intervention?

Table 4

Pre-intervention difference between the dominant and non-dominant side for different performance scores. Data are mean and 95% CI

	% dif. between sides ± 95 % CI	***P***	**Cohens *d***
Sub-maximal skiing economy	1.4 ± 0.8	.001	.10, very small effect
VO_{2peak}	1.7 ± 1.3	.01	.16, very small effect
TT_{3min} performance	5.8 ± 1.6	<.001	.49, small effect
Incremental speed test	6.2 ± 0.9	<.001	.86, large effect

Table 5

Relative differences for the speed test from pre- to post-intervention testing.

	Dominant side		**Non-dominant side**	
	P	**Cohens *d***	***P***	**Cohens *d***
Dyad	.365	.26, small effect	.744	.09, very small effect
Video	.972	.01, very small effect	.025	.65, medium effect
Coach	.312	.29, small effect	.007	.89, large effect
Control	.790	.08, very small effect	.077	.54, medium effect

Legends

Figure 1.

One cycle for G2 skating technique starting with pole plant on the strong side. Upper panel shows a side view (left) and top view (right) of the strong side to the right. Bottom panel shows a side view (left) and top view (right) of the strong side to the left. For most skiers one side is the dominant side, with the other being the non-dominant side.

Figure 2.

Upper panel: Overview of the experimental design. Bottom panel: Overview of the treadmill test session pre- and post-intervention. Submax. workloads 1a and 1b were performed at the same speed for all participants. Whether 1a or 1b was on the dominant side was randomized for each participant. Submax. workloads 2a and 2b were performed at ~88% of $\dot{V}O_{2peak}$ in the same order as 1a and 1b. All submaximal workloads were performed at 6° incline. Performance tests 1a and 1b were performed in the same order as the submaximal workloads at 8° incline. The order of dominant vs. non-dominant side followed the same order during the post-intervention tests.

Figure 3.

Upper panel: Percentage change score from pre- to post-intervention for the speed test. Grey area indicates the typical error of the test expressed as CV of 2.7%. Lower panel: Percentage change score from pre- to post-intervention for $\dot{V}O_2$ on dominant and non-dominant side during sub-maximal skiing. Grey area indicates the typical error of the test expressed as CV of 1.2% for adult athletes. Mean ± 95% CI. * significantly different from non-dominant side in DYAD controlled for pre-intervention scores. Circles represents individual percentage change scores. The green area indicates enhanced performance during intervention while the red area indicates decreased performance.

Declarations

Funding: This study was internally financed by the Department of Physical Performance at the Norwegian School of Sport Sciences.

Conflicts of interest: There are no conflicts of interest, including financial, consultant, institutional, or other relationships that might lead to bias or conflict of interest. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

Availability of data and material: The datasets generated for this study are available on request from the corresponding author.

Authors' contributions: OS, YO and TL designed the study. OS, KH, CS, TL performed the data collection. Data analysis was performed by OS, KH and CS. OS, YO and TL drafted the manuscript. All authors edited and revised the manuscript. All authors approved the final version of the manuscript.

Figure 1.

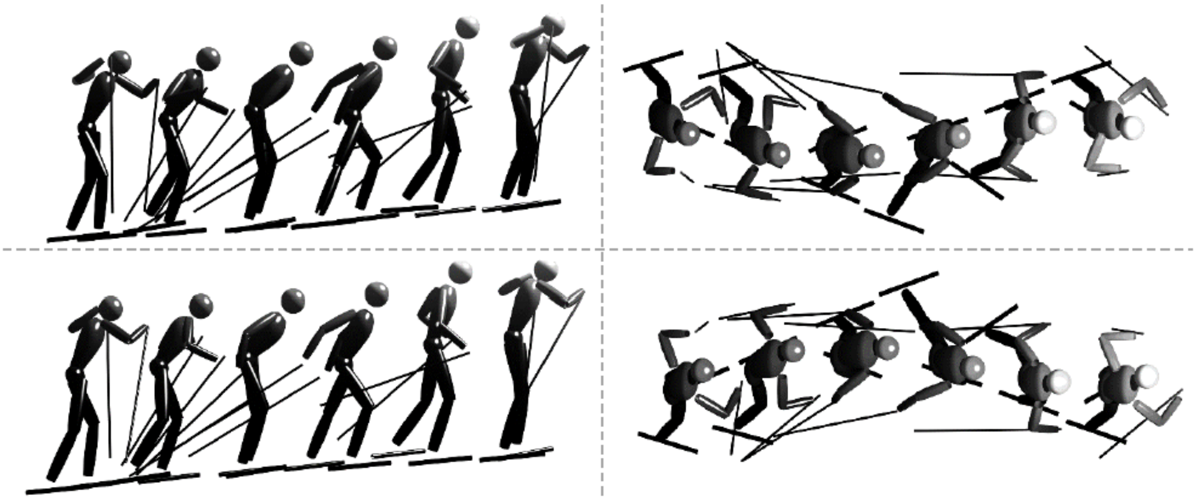


Figure 2.

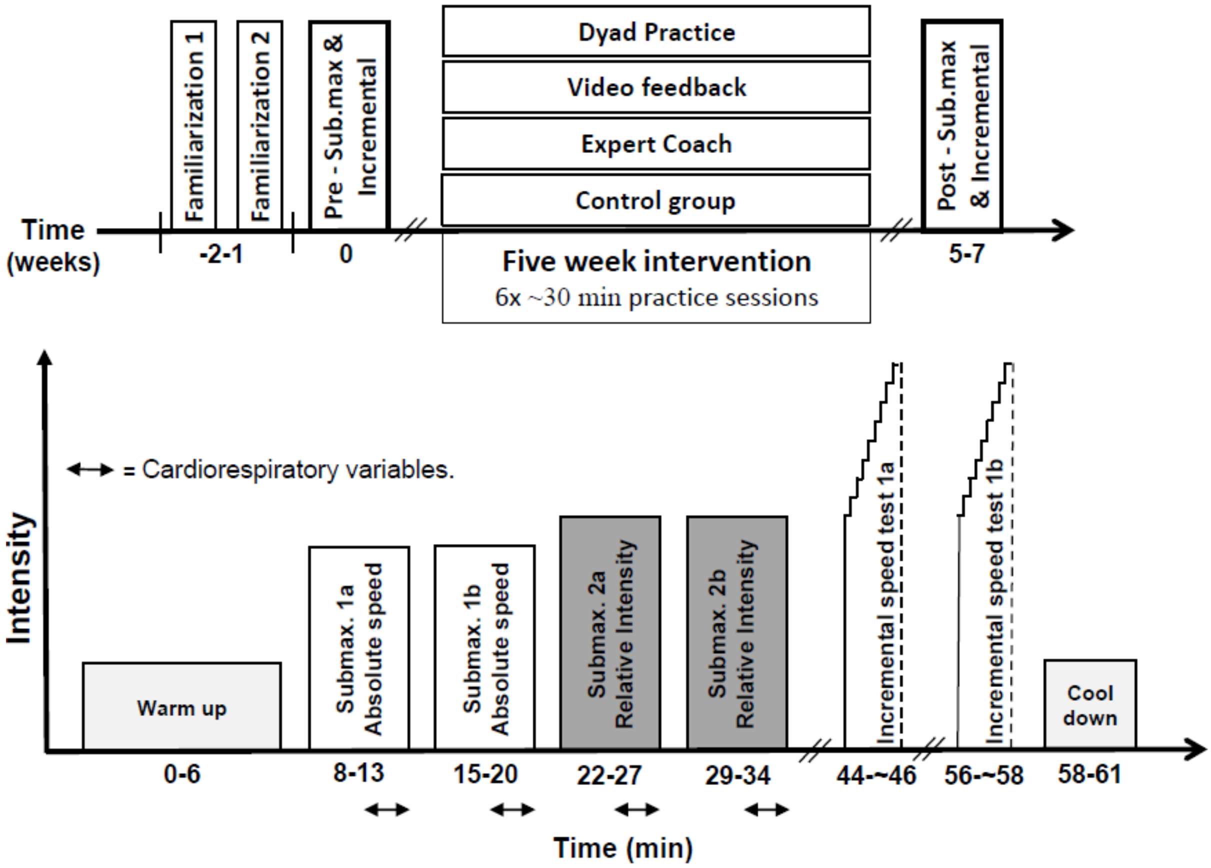
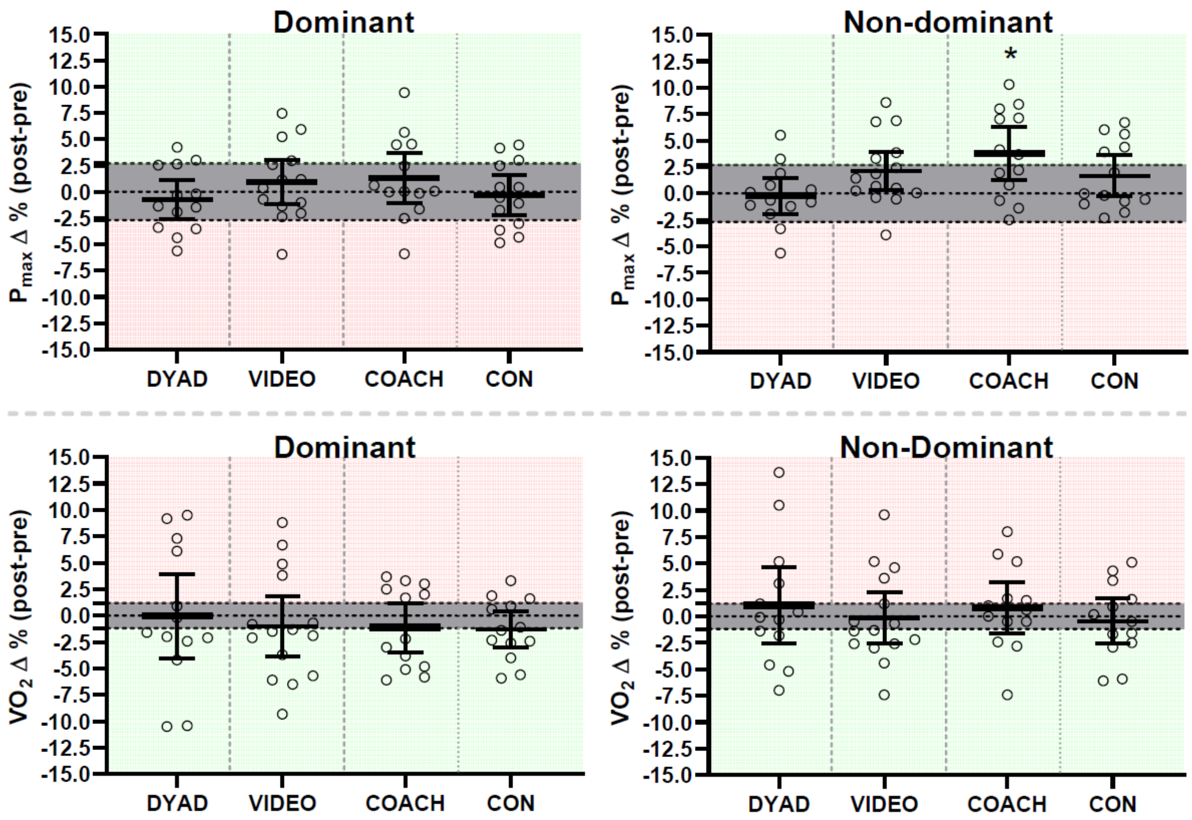

Familiarization 1
Familiarization 2
Pre - Sub.max & Incremental
Dyad Practice
Video feedback
Expert Coach
Control group
Post - Sub.max & Incremental
Time (weeks)
-2-1
0
Five week intervention
6x ~30 min practice sessions
5-7
Intensity
= Cardiorespiratory variables.
Warm up
Submax. 1a Absolute speed
Submax. 1b Absolute speed
Submax. 2a Relative Intensity
Submax. 2b Relative Intensity
Incremental speed test 1a
Incremental speed test 1b
Cool down
0-6
8-13
15-20
22-27
29-34
44-~46
56-~58
58-61
Time (min)

Figure 3.



Dominant
Non-dominant
P_{max} Δ % (post-pre)
Dominant
Non-Dominant
VO_2 Δ % (post-pre)
DYAD
VIDEO
COACH
CON