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Analysis of associations between selected sports performance factors and racing performance in the youth alpine skiing category

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Abstract

Introduction. **The research focuses on the analysis of associations between important motor skills that are essential for alpine skiing and performance in the youth category. The study came about in response to the fact that associations between individual concepts of motor abilities and performance in alpine skiing are not clearly described in the literature.** Aim of Study. **The research aimed to evaluate and identify possible associations between selected factors of sports performance, and actual performance of youth alpine skiers.** Material and Methods. **A group of 12 elite female Czech youth skiers (16-18 years old) was monitored for their training indicators, racing season performance, and selected sports performance factors (anthropometry, balance, laterality, muscle condition). To evaluate associations of monitored parameters, Spearman's correlation coefficient *r* was used.** Results. **The results of multiple analyses show no statistically significant correlation between anthropometric features and total FIS race performance. On the other hand, a statistically significant dependence was noted for specific training indicators (skiing hours, gate skiing) and FIS race performance. In the analysis of performance and monitored parameters (laterality, balance) of youth skiers no statistical dependence was found. Thus it may be assumed that the balance on both the dominant and non-dominant leg was the same, although muscle imbalances were identified among the skiers.** Conclusions. **From the obtained knowledge, we can state that alpine skiing is a complex sport, in which there is no unilateral overloading of the organism. To obtain excellent and steady results during a competition all the examined variables are more or less important for skiers. Without these abilities and skills, skiers' performance will never reach the maximum. Even though conditioning and skills are one of the main features of skiing, we should not forget about regeneration and compensation to prevent a risk of potential muscle imbalances or injuries among young athletes.**

KEYWORDS: balance, anthropometrics, alpine skiing, FIS score, muscle imbalances, lower limb laterality.

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Introduction

Alpine skiing, popular all over the world, is an extremely demanding and complex sport requiring a combination of technical, tactical, physical skills as well as high physiological capabilities in strength and endurance training. These factors determine skiers' performance. As a result, no aspect of the sport should be neglected [22]. Additionally, alpine skiing is a high-intensity sport, where lactate accumulation, muscle acidosis and muscle fatigue occur and influence the performance of skiers especially in terms of balance ability [13, 30]. The problem of balance and skiing results lacks sufficient research [18, 19], and the same applies to laterality and muscle imbalances. Therefore, we would like to fill this gap and find possible associations between them.

While a number of scientific papers concerning fine motor skills can be found in Anthropometrics and Development Psychology, it is surprising that almost none of them concerns the connection between alpine skiing and laterality [28], as laterality may play an important role in balance and skiers' performance. Balance has been accepted as one of the most important abilities in alpine skiing and it involves the skier attempting to maintain the center of his/her body vertically over the base support [10, 11, 12]. Elite skiers must fulfill immense physical requirements such as the engagement of the whole body in a streamline and aerodynamic position while making quick movements to make excellent turns [5]. All of these actions require skiers to maintain balance and overall control of their bodies, which requires good coordination of muscle structures in the trunk and lower body [9, 12, 23]. The study has also shown that balance is influenced by anthropometric features [1] and that fact led us to question whether anthropometric features are positively or negatively correlated between the two. Additionally, in terms of balance ability, the authors mainly focus on the relationship with injury cases; few studies explored the correlation between balance and performance [10]. Alpine skiing is a precise sport with a lot of requirements on the skier's body and mind. By monitoring the electromyographic activity of skiers' muscle structures, the researchers concluded that the *tibialis anterior*, *erector spinae*, *gluteus maximus*, *hamstrings*, and *quadriceps muscle groups* were the most engaged structures during elite skiing [9, 23]. Several antagonist muscle structures were shown to help with the stabilization of the knee and hip joints during skiing [9]. In these cases, any single muscle imbalance may limit the development of motor abilities and other skills and as a result affect the skier's sports performance. One study concluded that the importance of stretching is often neglected in alpine skiing [2]. In order to achieve the best results in a physically and mentally demanding sport such as alpine skiing, training needs to combine several aspects. The most common training types for alpine skiers are strength and core stability training, aerobic and anaerobic endurance, coordination, and balance. Competitive skiers combine this with supplementary training, often involving cross-training in other sports [12]. Therefore, our interest was to detect whether skiers take enough time to stretch and train antagonistic muscle pairs to prevent a potential risk of muscle imbalances and injuries, and to determine associations between different types of training and racing performance.

Aim of Study

The research aimed to evaluate and identify possible associations between selected factors of sports performance, and youth alpine skiers' performance.

Material and Methods

Participants

The sample of participants included a group of 12 elite female Czech youth skiers (16-18 years old). The participants were registered competitors in the U18 category in the Czech Republic and have raced for at least 10 years. Skiers in this category compete in slalom (S) and giant slalom (GS). Most of the competitors also competed in international events. Different teams across the Czech Republic were invited to participate provided that the competitors had to be ranked among the top 30 skiers in the 2018/2019 season. All competitors voluntarily participated in the testing after being informed of the purpose of the study. A written consent had to be signed prior to the study either by the participants themselves or by their parents.

Design

This study was conducted in specialized laboratories and under outdoor conditions. In this case, the outdoor conditions were mountains in the Czech Republic, where competitors took part in individual races included in this research. The skiers were monitored for their training indicators, performance in the 2018/2019 racing season, and selected sports performance factors (anthropometry, balance, laterality, muscle condition). Training indicators and performance were evaluated based on an analysis of training diaries and ranking lists of FIS races. The measurements were performed after the racing season. All measurements were obtained according to the WMA Declaration of Helsinki. The research was also approved by the Ethics Committee of the Faculty of Education, Jan Evangelista Purkyně University in Ústí nad Labem under no. 3/2019/02 on April 25, 2019.

Procedures

The testing included measurements of anthropometric variables, balance ability, laterality, muscle imbalance status, as well as evaluation of training performance and competition results.

Anthropometric measurements included height, weight, fitness score, basal metabolism level, skeletal muscle mass and body fat content. Anthropometric variables were evaluated on an In-Body 720 machine in the anthropometric laboratory of the Faculty of Physical

Culture (FPC), Palacky University in Olomouc. Muscular imbalances were also assessed in that laboratory. The shortening and weakening of muscles in individual parts of the human body were evaluated to determine the upper (UCS) and lower (LCS) crossed syndromes, including the evaluation of the foot arch and deformations in the foot area. The muscular apparatus examination was performed according to Dostalova [3]. The examination was performed on both sides of the body by a specialized physical therapist. The following muscles were examined: *m. iliopsoas*, *m. rectus femoris*, *m. tensor fasciae latea*, *m. triceps surae*, *mm. flexor genu*, *m. pectoralis major*, *mm. flexores nuchae*, *m. rectus abdominis*, *m. erector spinae*, *m. gluteus maximus*, *m. gluteus medius et minimus*, *mm. fixatorex scapulae inferiors*, *mm. abductors membri superioris*, *m. trapezius*, while arm stretch backward, side bend and forward bend examinations were also conducted.

In the biomechanical laboratory of the FPC, Palacky University in Olomouc, lower limb laterality and balance ability were evaluated on an AMTI force platform (type OR6-5, Advanced Mechanical Technology, Inc., Watertown, MA, USA, frame rate 200 Hz). Lower limb laterality was evaluated using three tests performed twice per each lower limb. The first test was a step onto a small box, the second test was a slight unexpected push from behind, where the participant had to maintain her stability, while the last test was an aimed kick between two cones. Balance was measured on three different surfaces, namely, the rigid platform of the force platform, a soft surface, which was mediated by a foam pad (Airex Balance Pad, Airex AG, Sins, Switzerland), and an unstable pad, which was secured by a balancing segment (ClassicR25V10, VSB – Technical University of Ostrava, Ostrava, Czech Republic). Firstly, before the testing participants tried each surface to establish their balance and feel comfortable. Then the participants took an initial position on the platform, which included standing straight on a dominant/non-dominant leg, as had been determined by the laterality tests, with the other leg bent at the knee and the foot pointing back. The arms were kept to the sides of the body and the participant looked straight forward at a point on the wall. Each test was performed twice for the dominant and non-dominant leg, lasting 30 seconds, with a 2-3-minute rest between tests. The surfaces of the platform were chosen randomly, but the dominant/non-dominant legs were alternated each time. The measurements of balance ability were calculated through the center of pressure (COP) position, which is the calculated value only from the forces acting on the pad. The COP position was calculated from the reaction force and torque according to the conversion formulas provided by the platform manufacturer. The COP coordinates were further filtered by a 4-way Butterworth low-pass filter with a 10 Hz cutoff frequency. The parameters of the COP movement were calculated as follows: Sway – a standard deviation of the COP position in each direction (medio-lateral and antero-posterior), Speed – an average speed of COP movement in each direction and overall. All balance calculations were performed in the Matlab software (v2018b, Mathworks, Inc., Natick, MA, USA).

Anthropometric measurements were performed at the beginning of the testing and they were followed by imbalance testing, determining laterality and balance performance.

Physical performance was determined by observation and competitive performance. Observation included the evaluation of training diaries, with summer and winter training taken in account (number of skiing hours, number of gates, endurance training hours, gym hours, functional training hours). Competitive performance was evaluated based on the skiers' ranking at the end of the season according to the FIS scores.

Statistics

The Shapiro–Wilk test showed variables as not normally distributed. Therefore, to evaluate associations of the monitored parameters Spearman's correlation coefficient *r* was applied. All the variables were analyzed using the Rstudio program, version 1.2.1335. Statistical significance was pre-determined as $p < 0.05$.

Results

Among the anthropometric measurements (Table 1), no significant correlation was found between the FIS

Table 1. Spearman's correlation between In-Body measurements and FIS score (coefficient *r*)

	FIS TS	FIS S	FIS GS
Height	0.45	0.46	0.48*
Weight	0.39	0.28	0.30*
Fitness score	0.21	0.09	0.11
Metabolic rate	0.53	0.46	0.48*
Muscle mass	0.52	0.44	0.45*
Fat mass	0.08	–0.02	–0.03

Note: FIS TS – FIS total score; FIS S – FIS slalom score; FIS GS – FIS giant slalom score
* statistically significant values

total score (TS) and the FIS S score. On the other hand, there were statistically significant values for the FIS GS score, where taller skiers obtained higher FIS scores than shorter ones. The same effect was identified for the competitor's weight.

The correlation results for the training and FIS scores indicated statistically significant relationships between the number of skiing hours and the number of gates trained throughout the whole year with FIS TS and FIS GS scores (Table 2). All of the other variables were not statistically significant.

Table 2. Spearman's correlation between observed types of training and FIS score (coefficient *r*)

	FIS TS	FIS S	FIS GS
Skiing	–0.80*	–0.72*	–0.75*
Gates	–0.75*	–0.65*	–0.69*
Endurance	–0.10	–0.16	0.41
Gym	0.48	0.35	0.44
Functional	–0.55	–0.53	–0.36

Note: FIS TS – FIS total score; FIS S – FIS slalom score; FIS GS – FIS giant slalom score
* statistically significant values

The level of balance on the dominant and non-dominant leg was determined as statistically non-significant. For that reason, it was assumed that the balance on both legs was the same. Another aspect tested in the study was the association between the skier's balance and performance (FIS TS, S, GS score), where either the dominant or non-dominant leg on different surfaces (rigid surface, foam pad, balancing segment) indicated a close correlation to the skier's performance (Table 3). Statistically significant values were found in giant slalom performance in a medio-lateral movement on both the dominant and non-dominant leg on the rigid platform.

Lastly, the UCS was diagnosed in 50% of cases (shortened – ascendant part of *m. trapezius* and *m. pectoralis major*, weakened – *m. longus colli*, *m. longus capitis* and *m. rhomboideus*). Slight muscle changes were diagnosed in 30% of the study participants. On the other hand, while no one was diagnosed with the LCS (shortened – *m. iliopsoas*, *m. rectus femoris*, *m. tensor fasciae latae*, *m. quadratus lumborum* and *m. erector spinae*, weakened – *m. rectus abdominis*, *m. gluteus maximus*, *m. gluteus medius* and *minimus*), some participants were close to developing it.

Table 3. Spearman's correlation between balance on different platforms and FIS score (coefficient r)

	FIS TS		FIS S		FIS GS	
	DL	NL	DL	NL	DL	NL
Rigid Platform						
Sway 1	0.48	0.28	0.38	0.22	0.78*	0.65*
Sway 2	0.15	0.32	0.14	0.44	0.37	0.50
Speed	0.26	0.35	0.26	0.37	0.54	0.58
Foam Pad						
Sway 1	0.33	0.27	0.28	0.24	0.52	0.64
Sway 2	0.07	0.03	–0.04	0.01	0.19	0.50
Speed	0.13	–0.27	0.09	–0.36	0.35	0.21
Balancing Segment						
Sway 1	0.22	0.37	0.22	0.42	0.58	0.75*
Sway 2	0.14	0.32	0.16	0.33	0.27	0.54
Speed	–0.14	0.08	–0.12	0.03	0.12	0.12

Note: FIS TS – FIS total score; FIS S – FIS slalom score; FIS GS – FIS giant slalom score; DL – dominant leg; NL – non-dominant leg; Sway 1 – standard deviation of the COP position in medio-lateral movement; Sway 2 – standard deviation of the COP position in antero-posterior movement; Speed – total average COP speed
* statistically significant values

Figure 1 displays muscles most commonly involved in skiing and the corresponding percentages of disability (weakened muscles – 0% *m. rectus abdominis*, 20% *m. gluteus medius* and *minimus*, 50% *m. deltoideus*, 60% *m. gluteus maximus*; shortened muscles – 30% *m. triceps surae*, 40% *m. biceps femoris*, *m. semitendinosus*, *m. semimembranosus*, *m. quadriceps femoris*, 60% *m. tibialis anterior*, *m. erector spinae*). The associations

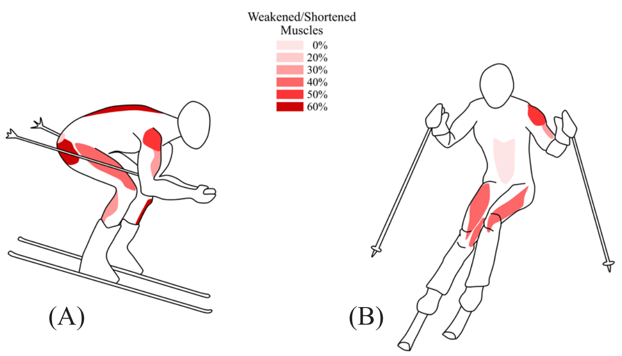

Figure 1. Overview of muscle imbalances on commonly involved muscles in skiing (A – downhill posture position, B – slalom posture position)

between the foot arch, deformations in the foot area and balance ability were not determined as statistically significant in any aspect, therefore those results are not presented.

Discussion

Regarding anthropometric variables, other studies reported different results. Lesnik and Zvan [14] aimed to determine the level of correlation between body dimensions and competitive success among 11- and 12-year old skiers and they confirmed that body weight and height parameters statistically influenced the skiers' performance. Conversely, Neumayr et al. [16] studied the anthropometric variables among skiers of the Austrian World Cup team in their mid-twenties and found no association between body height and weight, and skiers' performance. To widen the age range, our research included 16- to 18-year old skiers. We discovered an association connected to both body height and weight with skiers' GS competition performance. The results demonstrate that the heavier and/or taller a skier was the worse results she achieved. However, this may have been caused by the age of the skiers, their development, or abilities because the skiers have just gone through physical, mental, and cognitive changes. These changes might not help the skiers with their racing performance at all, because they have to adapt to new variables such as changes in coordination and overall body structures. The skiers' height may suddenly increase up to 10 cm per year and they may also gain weight. Weight gain is connected to the distribution of fat and muscle mass. Therefore, in this age category there are considerable performance differences between females and males [24, 25]. Another interesting aspect is connected with differences between slalom and giant slalom and their load intensity on the skier's organism. Slalom is the shortest event, lasting only 45–60 s with speeds ranging from 20 to 60 $km \cdot h^{-1}$. In slalom there are a total of 40–60 gates per run, with 4–13 m between gates. On the other hand, the giant slalom takes place in a relatively steep and undulating terrain. Giant slalom lasts 60–70 s with the speed range of 60–90 $km \cdot h^{-1}$, and the distance between gates of min. 10 m [17]. Hence height and weight might negatively influence giant slalom skiers' performance. Coordination for taller and heavier girls at higher speeds may be more challenging.

Another selected variable that affects racing performance is training. According to the skiers' training diaries, they trained frequently, focusing on different components. Even though skiers underwent most of the training types suggested by Hydren et al. [12], we still found no association between individual types of training and skiers' performance. The reason is that all types of training are part of the performance. Without these certain types of training, the skiers would not be able to obtain such results. For that reason, alpine skiing is identified as a complex sport.

The research on the Training of Olympic Alpine Ski Racers presents the number of training sessions for functional training, endurance training and the gym. Gilgien et al. [7] stated that functional training is performed most frequently throughout the week (average 8 sessions per week), followed by endurance training and the gym. This confirms our findings that functional training may be considered the most efficient training method for alpine skiers. Our youth skiers participate in functional training on average 3 times per week. It must be taken into consideration that our participants were not elite professional competitors, therefore they did not train as many hours as Olympic athletes. It is crucial to point out that during functional training most of the muscles work intensively and dynamically, which is one of the features of skiing. Consequently, it appears to be an effective way to train in alpine skiing.

Also endurance training is essential for skiers. It consists of numerous short training runs [7, 21], as it helps to recover faster between each run and sessions. Without advanced endurance abilities skiers reach their limits quickly and fatigue can severely limit the training and learning process. Also, fatigue decreases performance in terms of physical and technical aspects [21].

Additionally, Olympic alpine skiers train and compete for approximately 130-150 days a year. The total volume of their training is distributed according to the disciplines, in which the skier specializes [7]. In our case, the youth skiers trained and competed for 100-130 days of the year. Our participants mainly trained the technical disciplines, i.e. slalom and giant slalom, as for safety reasons these are the only disciplines performed in their age category.

The study also tried to identify possible associations between balance on the dominant and non-dominant leg and skiers' performance. Firstly, balance needed for skiing is difficult to evaluate in laboratories, because athletes frequently make adjustments due to internal and external forces. It is a challenging task to choose the appropriate testing technique [17]. As previously mentioned, it is difficult to create real snow conditions in a laboratory. For that reason, we tested our participants on different platforms to see if there was any association. Secondly, it is challenging to evaluate and calculate results from one competition in alpine skiing, as not all skiers might finish the race [8, 27]. Accordingly, we took into consideration the results from the entire season (total FIS score). Thirdly, studies have shown that balance is influenced by anthropometric features. Therefore, skiers who lack balance probably quit the competitive environment, because there were already unsuccessful in lower age categories [1].

Another factor in this study was laterality. Surprisingly, alpine skiing laterality was only examined in terms of knee injuries [28], while Vaverka and Vodickova investigated it as an aspect of ski turning by [29]. In our research, we took into consideration all of the facts mentioned above. In our findings, we confirmed that there was no correlation between the dominant and non-dominant leg. Also, no such relationship was confirmed in balance ability. It would be worthwhile to evaluate more participants, potentially adding dynamic testing on the platform to see whether in some situations balance can help skiers. For athletes with a history of injuries or those who suffer from some sort of chronic injury, good balance and the accompanying training are an essential part of recovery. However, it is not always easy for skiers to incorporate this into their busy training schedule [4, 6].

Other issues related to injuries include stretching and muscle imbalance. Studies concluded that the importance of stretching is often neglected in alpine skiing. Research showed that stretching is a crucial tool for skiers to improve flexibility and elasticity, which helps with a range of motion in the joints, injury prevention (cold and unstretched muscles are more likely to tear) and fluid body movement (it promotes dissipation of lactic acid in muscles) [2, 26]. It was proven in a longitudinal study that the risk of ACL injury is greater in female athletes. This finding suggests that core strength is a predominant critical factor for ACL injuries in young ski racers [20]. Another common injury is caused by overusing the muscles of the lower back. It is caused by the volume of mechanical overloading and the specific sports patterns where skiers are involved in forward, backward, and sideways bending, as well as torsion in the pre-load spine [15].

Overall, we can confirm that certain muscle imbalances may lead to future injuries if they are not compensated. All of the study participants were girls and interestingly none of them had problems with core strength. Hopefully, this means they are unlikely to experience any ACL injuries in the future. When we talk about mechanical overloading of the skier's body, it applies to the required posture of the skier while racing or training. Fifty percent of our participants were diagnosed with the upper crossed syndrome that comes from this specific posture when the stretching and exercising were inappropriate. Twenty percent of the participants were diagnosed with no muscle imbalance changes, whereas the remaining 30% were diagnosed with slightly weakened and shortened muscles. On the other hand, we cannot talk about the lower crossed syndrome, as it was not diagnosed in any of the participants. Nevertheless, most of the skiers have weakened *m. gluteus maximus* and shortened *m. rectus femoris*, *m. tensor fasciae latae* and *m. erector spinae*. This resulted from the bending position, where these muscles are overloaded and not compensated enough. Therefore, compensation should be applied as soon as possible to prevent the skiers from developing the lower crossed syndrome.

Conclusions

Based on the obtained data we can state that alpine skiing is a complex and challenging sport, in which many variables can play a role. Within the anthropometrics and performance correlation, we identified a negative correlation between achieved results and both the weight and height of the skier. This means that the heavier and/or taller the skier was, the worse results she achieved. The analysis also showed that among the observed skiers functional training is considered as the most efficient training method for alpine skiers' performance. No correlation was observed between measures of balance and laterality with performance. Lastly, we found that half of the tested skiers had the upper crossed syndrome, which can be explained by poor stretching and muscle overload in the skiing position.

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Conflict of Interests

The authors declare no conflict of interest.

References

1. Claessens AL, Lefevre J, Beunen G, Malina RM. The contribution of anthropometric characteristics to performance scores in elite female gymnasts. J Sports Med Phys Fitness. 1999;39:355-360.
2. Czarnecki G. 6 keys to stronger skiing. Snow Country. 1991 Oct:34.
3. Dostálová I. Zdravotní tělesná výchova ve studijních programech Fakulty tělesné kultury (Health physical education in the study programs of the Faculty of Physical Education). Univerzita Palackeho v Olomouci; 2013:94-120.
4. Fasel B, Sporri J, Gilgien M, Boffi G, Chardonnens J, Muller E, et al. Three-dimensional body and centre of mass kinematics in alpine ski racing using differential GNSS and inertial sensors. Remote Sens. 2016;8. DOI: 10.3390/rs8080671.
5. Ferguson RA. Limitations to performance during alpine skiing. Exp Physiol. 2010;95:404-410. doi:10.1113/expphysiol.2009.047563.
6. Gilgien M, Kroll J, Sporri J, Crivelli P, Muller E. Application of dGNSS in alpine ski racing: basis for evaluating physical demands and safety. Front Physiol. 2018;9:145-145. doi:10.3389/fphys.2018.00145.
7. Gilgien M, Reid R, Raschner C, Supej M, Holmberg H-C. The training of Olympic alpine ski racers. Front Physiol. 2018;9:1772. doi:10.3389/fphys.2018.01772.
8. Hebert-Losier K, Supej M, Holmberg H-C. Biomechanical factors influencing the performance of elite alpine ski racers. Sports Med. 2014;44:519-533. doi:10.1007/s40279-013-0132-z.
9. Hintermeister RA, O'Connor DD, Dillman CJ, Suplizio CL, Lange GW, Steadman JR. Muscle activity in slalom and giant slalom skiing. Med Sci Sports Exerc. 1995;27:315-322.
10. Hrysomallis C. Balance ability and athletic performance. Sports Med. 2011;41:221-232. doi:10.2165/11538560-000000000-00000.
11. Hydren J, Kraemer W, Volek J, Dunn-Lewis C, Comstock B, Szivak T, et al. Performance changes during a weeklong high-altitude alpine ski-racing training camp in lowlander young athletes. J Strength Cond Res. 2013;27:924-937. doi:10.1519/JSC.0b013e31827a9c62.
12. Hydren J, Volek J, Maresh C, Comstock B, Kraemer W. Review of strength and conditioning for alpine ski racing. Strength Cond J. 2013;35:10-28. doi:10.1519/SSC.0b013e31828238be.
13. Ju Y-Y, Wang C-W, Cheng H-YK. Effects of active fatiguing movement versus passive repetitive movement on knee proprioception. Clin Biomech. 2010;25:708-712. doi:10.1016/j.clinbiomech.2010.04.017.
14. Lesnik B, Zvan M. The influence of body dimensions on success in younger categories in alpine skiing. Res Phys Educ Sport Health. 2014;3:3-8.
15. Muller E, Kroll J, Lindiger S. Science and Skiing VI. Maidenhead, UK: Meyer & Meyer Sport; 2014.
16. Neumayr G, Hoertnagl H, Pfister R, Koller A, Eibl G, Raas E. Physical and physiological factors associated with success in professional alpine skiing. Int J Sports Med. 2003;24:571-575. doi:10.1055/s-2003-43270.
17. Nilsson R. Competitive Performance prediction of elite alpine skiers. Doctoral dissertation. Umeå University, Faculty of Medicine, Department of Community Medicine and Rehabilitation; 2019.
18. Noe F, Paillard T. Is postural control affected by expertise in alpine skiing? Br J Sports Med. 2005;39:835-837. doi:10.1136/bjsm.2005.018127.
19. Platzer H-P, Raschner C, Patterson C, Lembert S. Comparison of physical characteristics and performance among elite snowboarders. J Strength Cond Res. 2009;23:1427-1432. doi:10.1519/JSC.0b013e3181aa1d9f.
20. Raschner C, Platzer H-P, Patterson C, Werner I, Huber R, Hildebrandt C. The relationship between ACL injuries and physical fitness in young competitive ski racers: a 10-year longitudinal study. Br J Sports Med. 2012; 46:1065. doi:10.1136/bjsports-2012-091050.
21. Rieder M, Fiala M. Skiing Fitness: Conditioning Training for Ski Sports. Maidenhead, UK: Meyer & Meyer Sport; 2005.
22. Schoenhuber H, Panzeri A, Porcelli S. Alpine Skiing Injuries: Prevention and Management. Cham, Switzerland: Springer International Publishing; 2018.
23. Supej M, Kipp R, Holmberg H-C. Mechanical parameters as predictors of performance in alpine World Cup slalom racing. Scand J Med Sci Sports. 2011;2:72-81. doi:10.1111/j.1600-0838.2010.01159.x.
24. Susman E, Rogol A. Puberty and psychological development. Handbook of Adolescent Psychology. New York, NY: John Wiley & Sons; 2004, pp. 15-44.
25. Steinberg L. Adolescence. New York, NY: McGraw-Hill Education; 2008.
26. Thomas G. Performance Skiing: Training and Techniques to Make You a Better Alpine Skier. Mechanicsburg, PA: Stackpole Books; 1992.
27. Turnbull JR, Kilding AE, Keogh JWL. Physiology of alpine skiing. Scand J Med Sci Sports. 2009;19:146-155. doi:10.1111/j.1600-0838.2009.00901.x.
28. Urabe Y, Iwamoto H, Koshida S, Tanaka K, Miyashita K, Ochi M. Does Laterality Exist in ACL Injury Prevalence in Alpine Skiers? In: Johnson R, Shealy J, Langran M, editors. Ski Trauma Saf. 2009; 17:147-153.

29. Vaverka F, Vodickova S. Laterality of the lower limbs and carving turns. Biol Sport. 2010;27:129-134. doi:10.5604/20831862.913080.
30. White GE, Wells GD. The effect of on-hill active recovery performed between runs on blood lactate concentration and fatigue in alpine ski racers. J Strength Cond Res. 2015;29:800-806. doi:10.1519/JSC.0000000000000677.