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Research article

SECULAR TRENDS OF PHYSICAL FITNESS IN ELITE YOUTH ALPINE SKIERS: AN ANALYSIS OF PERFORMANCE IN 2013 AND 2023

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Abstract. *This study compares physical fitness performance and determined secular trends in elite youth alpine skiers tested in 2013 and 2023. One hundred forty elite youth alpine skiers, aged 12 or 13 years, participated in this study. 30 boys and 25 girls were tested (n = 55) in 2013, whereas in 2023 the sample included 47 boys and 38 girls (n = 85). Elite male youth skiers showed a significant change only in speed performance over 20 meters ($p < 0.05$). In contrast, female skiers demonstrated significant improvements in explosive power, anaerobic performance and speed (all $p < 0.05$). Over the last decade, elite U12–U13 alpine skiers have maintained or modestly increased most key fitness attributes, with girls showing wider-ranging improvements than boys.*

Key words: *skiing, fitness, trends, performance, snowsports*

1. INTRODUCTION

Elite youth alpine skiing is a highly challenging sport discipline where boys and girls train and compete in very demanding conditions despite being only 11-13 years old (Steidl-Müller et al., 2019). Consequently, they learn early to handle fast speeds, rapid edge changes, and long competition days at altitude. National ski federations invest strongly in these age groups because results in the under-12 and under-13 (U12–U13) categories often predict later success in senior categories (DeCouto et al., 2021). In

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addition, despite coaches collecting split times and video for many races, there is little systematic information about how basic physical fitness has evolved over recent years.

Over the past decade, many authors have tried to describe secular trends in the physical fitness of young athletes (Gonaus et al., 2019; Nevill et al., 2023; Sun et al., 2025). Some studies showed small but steady gains in sprint-related or anaerobic performance due to advanced technology implementation and appropriate training load monitoring, which strongly impact speed development in youths (Tomkinson & Olds, 2007). In contrast, some authors confirmed relatively stable or even slightly lower values for endurance performance, perhaps linked to athletes exerting maximal levels for a long time. Taken together, findings related to secular trends in athletes' physical fitness are inconclusive, and it is still unclear whether the overall fitness of talented boys and girls has really improved, stayed the same, or even declined during the last ten years.

Previous studies emphasized that for elite youth alpine skiers, anaerobic endurance, explosive power, agility, and speed are the most important physical fitness parameters directly related to competitive success (Steidl-Müller et al., 2021; Stielow, 2010). For example, anaerobic endurance is extremely important for finishing long training days at altitude or repeating several competitive races consecutively, while lower-limb explosive power is needed to accelerate out of gates (Bertozzi et al., 2023; Turković et al., 2020). On the other hand, appropriate agility and straight-line speed are necessary for quick edge changes and flat glide sections, respectively (Turković et al., 2020). Despite their clear relevance to race performance and injury prevention, long-term studies focusing on secular trends in this age group are scarce.

It is well known that competitive demands have changed fast, even for youth categories, whereas races are shorter but more technical, ski materials evolve almost every season, and whole-year training camps are now common (Bertozzi et al., 2023). However, scientific evidence-based monitoring is not in line with these changes. In daily work with youth ski academies, many practitioners notice that today's skiers seem to jump higher and turn faster than their peers did ten years ago (Gorski et al., 2014; Steidl-Müller et al., 2021). This field impression suggests a possible shift in the balance of fitness performance, but there is a need for systematic data collection to prove such a subjective observation.

Therefore, the aim of this study was to compare physical fitness performance in elite youth alpine skiers tested in 2013 and 2023. We hypothesized that (i) explosive power and speed would show moderate improvements, reflecting evidence-based strength and conditioning approaches in regular training, (ii) endurance would remain unchanged, and (iii) agility would improve only marginally because baseline levels were already high among elite alpine skiers.

2. METHODS

2.1. Participants

One hundred forty elite youth alpine skiers, aged 12 or 13 years, participated in this study. 30 boys and 25 girls were tested (n = 55) in 2013, whereas in 2023 the sample included 47 boys and 38 girls (n = 85). All skiers were enrolled in a national talent program and had completed at least three years of organized ski-specific training. The testing procedures were explained to each skier and their parent or legal guardian, who provided written informed

consent. The Faculty Ethics Committee approved the study, which was conducted in accordance with the Declaration of Helsinki.

Table 1 General distribution of the participants

		N	%
Year of birth	2000	24	17.1
	2001	31	22.1
	2010	52	37.1
	2011	33	23.6
Gender	Boys	77	55.0
	Girls	63	45.0

2.2. Procedure

All measurements were completed indoors and outdoors with a similar wooden or synthetic sports floor to keep the surface and temperature unchanged for both test years. Assessments were completed in the morning hours between 09:00am and noon, with athletes arriving in small groups to reduce waiting time. Upon arrival, youth skiers performed a standardized 15-minute warm-up that included five minutes of easy jogging, dynamic joint-mobility drills for the hips, knees, and ankles, and three sub-maximal accelerations over 30 m. After the warm-up they rested for three minutes before starting the test battery. To minimize fatigue effects, the order of tests was the same for every athlete, including lower limb explosive power, agility, speed, and then anaerobic endurance.

Explosive power. Lower-limb explosive power was first assessed with the standing long-jump test. From a fixed two-footed take-off behind a marked line, each skier completed 10 consecutive jumps as far as possible while keeping their feet together during landing. The distance from the starting line to the last heel position was recorded at the nearest 0.01 centimeter, and the best of three attempts was used for analysis. Explosive power in the horizontal plane was further examined by the standing triple jump. Athletes executed three consecutive bilateral hops, striving for maximum total distance while maintaining balance at landing. Measurement procedures matched those of the long-jump, and the best of three trials counted.

Anaerobic performance. Anaerobic endurance capacity was assessed with a 400-m all-out run performed on an outdoor, eight-lane synthetic track. Each skier started from a standing position one meter behind the electronic timing gate, completed one full lap as fast as possible, and received consistent verbal encouragement along the back straight. Performance time was recorded with dual-beam photocells accurate to 0.01 s, and the single trial completed by each athlete was used for analysis.

Agility. Agility was evaluated using the Figure-eights test completed around nine cones. Nine cones were arranged in a three-by-three grid with two-meter spacing. Starting in the center, the skier weaved in a continuous figure-eight pattern around the outer cones for two full circuits before returning to the center cone. Dual-beam photocells captured total time, accurate to 0.01 s.

Speed. Maximum sprinting speed was measured with a 20-metre straight-line sprint. Sprint speed was assessed over a 20 m distance from a standing start position. Photocell timing gates (Witty, Microgate, Bolzano, Italy) set 1 m above the ground were placed at 0 and 20 m. Players began each run 20 cm behind the first beam to avoid premature activation. Each skier performed two sprints with full recovery, and the fastest run was recorded.

2.3. Statistical analysis

Data analysis was performed using the Statistical Package for the Social Sciences (v13.0, SPSS Inc., Chicago, IL, USA). Means and standard deviations (SD) were calculated for each variable. Differences in physical fitness performance measured in 2013 and 2023 were calculated using a T-test. Statistical significance was set at $p<0.05$.

3. RESULTS

The decade secular trend comparison showed clear gender-specific patterns. In boys, the only variable that showed a statistically significant difference between 2013 and 2023 was maximum sprinting speed over 20 m ($p < 0.001$). Although the standing long jump, 400-m run, agility, and standing triple jump showed a tendency for small mean changes, none were statistically significant (Table 2).

In contrast, four tests demonstrated significant difference in elite female youth alpine skiers. Compared with their 2013 counterparts, the 2023 female skiers jumped farther in the ten-repetition standing long jump, covered the 400m distance faster, produced longer distances in the standing triple jump, and recorded superior 20-m sprint performance ($p \leq 0.01$). Only the agility did not show a significant difference between 2013 and 2023. The magnitude of improvement was especially pronounced for explosive power, with average increases of about 7 % in both horizontal jumping tests, and a 3–4 % reduction in 400-m time, underscoring broader advances in anaerobic capacity and neuromuscular function.

Table 2 Physical fitness performance parameters in 2013 and 2023 in elite male and female alpine skiers

	Girls					Boys			
	Year	N	Mean	SD	p-value	N	Mean	SD	p-value
10 Long jumps (m)	2013	25	18.71	1.57	**0.00**	30	19.86	2.23	0.90
	2023	28	20.05	1.57		47	19.80	2.23	
400-meter run (s)	2013	25	80.32	4.92	**0.01**	30	79.25	7.46	0.19
	2023	38	77.48	6.87		47	77.89	10.94	
Agility (s)	2013	25	33.60	1.75	0.19	30	33.45	2.59	0.70
	2023	38	32.86	2.44		47	33.24	2.06	
Triple jump (cm)	2013	25	555.64	45.47	**0.00**	30	581.10	64.35	0.36
	2023	38	593.32	52.84		47	588.06	54.94	
Speed 20m (s)	2013	25	4.61	0.72	**0.00**	30	5.08	0.93	**0.00**
	2023	38	6.91	0.35		47	6.71	0.46	

4. DISCUSSION

This study aimed to determine whether the physical fitness levels of elite under-12 and under-13 alpine skiers changed between 2013 and 2023. Major findings of this study showed that girls tested in 2023 outperformed their 2013 counterparts in explosive power, anaerobic performance, and speed. In contrast, boys showed a significant difference only in the 20-m sprint. Agility remained statistically unchanged in both sexes. These data suggest a sex-specific shift in training effects or athlete selection over the last ten years and provide timely criteria for youth-development programs.

Explosive power is very important for professional alpine skiers due to its strong correlation with performance (Müller et al., 2015). The girls' group showed an increase of 1.3 m over ten consecutive standing long jumps and ~38 cm in the standing triple jump values, comparable to the improvements of 5–10 % over the decade observed in Austrian U10–U15 ski racers (Steidl-Müller et al., 2020). On the other hand, boys did not show a statistically significant change, which is in line with a previous study observed in Swiss male skiers between 2004 and 2011 (Gorski et al., 2014). Improved neuromuscular coordination and targeted plyometrics could underpin these improvements in female alpine skiers. In contrast, early-maturing boys may already express close-to-maximal jump power at 12–13 years, leaving lower possibilities for gains in the later stage of their athletic development.

Both sexes sprinted faster over 20 m in 2023, but the relative change was larger in boys (-0.37 s, -7 %) than in girls (-0.30s, -6 %). A greater focus on individual-based sprint methods, which are very common nowadays due to the frequently used technology for training monitoring, is one of the reasons for the significant improvements in both genders. In addition, use of timing gates for feedback may have accelerated start mechanics, particularly in boys who often prioritize speed drills. Gorski et al. (2014) found that sprint and coordination test scores in young Swiss skiers improved markedly once such tests became part of the national evaluation battery, supporting the familiarization process and the idea that the testing battery has to be very specific.

Agility is not a highly demanding physical fitness parameter in alpine skiing, as in other team sports. Neither boys nor girls demonstrated significant improvements in agility performance over a one-decade period. Two factors may explain the very similar performance. First, the baseline levels observed in 2013 were already high, leaving limited possibility for additional improvements over the year because skiers reached their genetic potential earlier. Second, modern ski-specific agility drills (e.g., parkour lines, slacklining) focus on movement variability rather than absolute completion time, potentially reducing test-specific practice applied in this study. Steidl-Müller et al. (2020) suggested that coordination-oriented training produces injury-protection even when timed agility scores remain stable.

Despite several significant findings in this study, some limitations should be pointed out. Firstly, only two cross-sectional time points were analyzed in this study, therefore, some long term comparisons remain unknown. Secondly, biological maturation was not measured in both periods, so physical fitness performance was not controlled by the impact of growth and maturation. Third, our sample represents a single national program, and findings may not generalize to systems with different selection procedures or training volumes. Future research should integrate maturity status and on-snow performance metrics to clarify how secular fitness changes translate into competitive success.

To conclude, the data suggest that training and/or selection processes over the last decade have led to measurable progress in several key fitness attributes among elite U12–U13 skiers.

Improvements in male youth skiers were limited to sprint speed, while improvements in female skiers were broader, including explosive power, anaerobic performance, and speed. These findings raise the possibility that male athletes approached a performance peak earlier. In addition, recent athletes' equality programs and initiatives have favored the development of female skiers because females were not equally represented ten years ago compared to nowadays.

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SEKUNDARNI TREND FIZIČKOG FITNESA ELITNIH SKIJAŠA: ANALIZA SPOSOBNOSTI 2013 I 2023

Ova studija je upoređivala fizički fitness i utvrđivala sekundarni trend elitnih skijaša koji su testirani 2013 i 2023. godine. Sto četrdeset elitnih alpskih skijaša, starosti 12-13 godina, je učestvovalo u ovoj studiji. Trideset dečaka i dvadeset pet devojčica (n=55) je testirano 2013. godine, dok je 2023. godine testirano 47 dečaka i 38 devojčica (n=85). Elitni mladi skijaši su pokazali značajan trend promena u brzini u poslednjih deset godina. Nasuprot tome, kod skijašica je utvrđena statistički značajna razlika u eksplozivnoj snazi, anaerobnim sposobnostima i brzini ($p<0.05$). U poslednjih deset godina, elitni skijaši starosti 12-13 godina održavaju ili umereno povećavaju svoje fitness sposobnsoti sa naglaskom na značajnije povećanje kod skijašica u odnosu na skijaše.

Ključne reči: *skijanje, fitnes, trend, sposobnosti, snežni sportovi*