4-30-2021

Fitness testing parameters for alpine ski racing

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10.1519/SSC.0000000000000587
This is a non-final version of an article published in final form in Pritchard, J. J. (2021). Fitness testing parameters for alpine ski racing. *Strength and Conditioning Journal, 43*(2), 1-6. https://doi.org/10.1519/SSC.0000000000000587
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Fitness Testing Parameters for Alpine Ski Racing

Key words: ski-racing, skiing physiology, skiing biomechanics

Summary

Alpine ski racing requires high levels of isometric, eccentric and concentric muscle actions through wide ranges of hip, knee, and ankle mobility. The course duration of ~40 seconds for slalom racing to upwards of 2.5 minutes for downhill racing necessitates high levels of anaerobic endurance, aerobic power, and force to production in order to be successful. In addition, due to the highly technical skill aspect of ski racing, neuromuscular coordination is of utmost importance. This review identifies the most effective performance testing methods for alpine ski racing, as well as highlighting their relevance to the physiological parameters of the sport.

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Introduction

Performance testing should directly relate to physiological parameters of the sport it is measuring, as well as provide detailed information on the reliability and validity of the protocols implemented. Effective testing measures are founded on movement analyses, physiological assessments, injury/risk assessments, and athlete population needs (25). Through an effective battery of testing, athlete strengths and weaknesses can be identified to serve as the foundation for future programming. In addition, regular testing quantifies the training effect on the targeted physiological qualities of each athlete when planned appropriately. Furthermore, the aim of testing is to provide evidence-based advice to coaches and athletes, thus it must be reliable and valid, as well highly repeatable (31). Tanner et al. (31) contend that a systematic approach to collection, processing, analysis, and reporting of testing data is needed. Data is only as good as the collection methods used to gather them, as well as the statistical testing and analysis used to quantify the meaning or results.

The sport of alpine skiing requires an array of physiological and technical characteristics in order to be successful. The four major racing events, Slalom (SL), Giant Slalom (GS), Super Giant Slalom (SG), and Downhill Racing (DH) share similar characteristics in their physiological requirements but vary slightly in their specific muscle actions and energy system demands. Alpine ski racers use high levels of isometric, slow eccentric, and slow concentric muscle actions, making it rather unique in comparison to other sports due to the high levels of muscle co-contraction (9). Successful alpine ski racers demonstrate high levels of aerobic power ($VO2_{max}$), anaerobic endurance, neuromuscular coordination, and force generating capabilities (35). No single fiber type is predominant among alpine ski racers, as substantial variation exists between individuals, however, higher levels of type I fibers seem to be predominate (34). With an understanding of what alpine skiing demands, it can be concluded that a carefully selected battery of tests is essential in order to monitor results among the athletes. The competitive season for most World Cup Alpine Ski Racers spans from late November to early April, thus testing throughout the season is critical to ensure athletes are maintaining their important physiological qualities and not trending toward injury (28). After a brief transition period following the competitive season, testing can be conducted in late April or early May to establish baseline performance characteristics, as well as define the degree to which training residuals have atrophied over the course of the season (25). Depending on the allotted time in which an athlete can spend in formal training at a dedicated location with qualified staff, another battery of tests should be conducted mid-summer to evaluate progress in the desired attributes. At this time, aerobic capacity and anaerobic endurance should be greatly elevated through the appropriately concentrated blocks of training (25). A third and final battery of tests should be conducted in late October or early November, just prior to the commencement of on-hill snow training. This series of tests provides a final assessment of the progression which athletes made through off-season training, as well as their projected safety or injury risk for the competition season. Athletes should be tested throughout the competitive season when it aligns with their schedules and preparedness to ensure training interventions are maintaining important physiological qualities (25).

The purpose of this review is to discuss performance tests that relate to the physiological characteristics of alpine skiing, the reliability/validity attributed to them, and the most effective manner in which to implement them.

Movement Analysis

Alpine skiing demands high levels of neuromuscular coordination, particularly in the carved turn, which is arguably the most critical aspect to racing. Carved turning is the resistance of generated force through the maintenance of edge control and balance requiring adequate levels of lower body dexterity (15, 30). This movement is often broken into four critical stages: initiation, turning, completion, and transition.

Hydren et al. (15) summarize the initiation phase as the point where the shoulder closely clears the gate and the athlete's body weight is supported by the rolled ski edge of each uphill and outside leg. The turning phase happens when the shoulder returns parallel with the snow surface while the outside leg remains extended and the inside leg bends in order to move the hips closer to the snow for a higher edge angle (15). After that, the completion phase is seen by the bending of the outside leg and rising of the hips which reduces the edge angle of the skis (15). Finally, the transition phase is where the feet glide under the hips moving downhill, ultimately transferring the skier's body mass from the downhill to uphill ski (15). This process is repeated sequentially throughout the course, and the velocity/forces encountered by the athlete depend on the slope of the hill as well as the discipline being raced.

Figure 1- Phases of a typical carved turn in an alpine ski racing course (15).

Forces generated during turns typically range between 1 and 2.5 g (sometimes getting as high as 3 g; g = gravity), occurring primarily through the forefoot as this is the primary driver of steering (6, 15). Throughout a turning motion there is knee flexion (eccentric force), static contractions (isometric force), and knee extension (concentric force). During turning, average knee angular velocity is approximately 69 °/ s +/- 11 ° / s for SL; 34 ° / s +/- 2 ° / s for GS; and approximately 17 °/ s for SG (6, 15). This is exceptionally slower than a running gait which is ~300 °/ s and a sprinting gait which is ~650 °/ s, attesting to the slower nature of muscle contraction involved in alpine skiing (34). The time in which a turn is completed is approximately 1.6 s for SL, 3.5 s for GS, and 4.1 s for SG (34). Turnbull et al. (34) add that near maximal voluntary muscle contractions are seen in SL racing, ultimately reducing muscle blood perfusion, suggesting that insufficient strength limits a skier's ability to maintain posture and withstand high forces.

Additional biomechanical factors that influence performance are energy dissipation and conservation throughout each turn, aerodynamic drag and frictional forces, ground reaction forces, turn radius, and trajectory of the skis' center of mass (13). SL and GS are typically affected by earlier initiation of turns, longer path length and trajectory, and earlier, smoother ground reaction force carving (2, 8). Speed skiing (DH) is affected by minimizing aerodynamic drag and maintaining a tightly tucked position throughout the course. Additionally, Federold et al. (8) conducted a research study to examine the impact of skier action on the gliding times during races. Analyses of 68 recorded runs show the run times are affected by edging of the skis, not forward and backward lean, contrary to belief (8). This is due to the increased ski-snow friction, suggesting that skiers should minimize edging when possible in gliding sections of the race to increase performance (8).

In conclusion, alpine skiing requires an array of slow eccentric and concentric muscle contractions combined with periodic isometric muscle contractions at relatively slow knee angular velocities. Biomechanical factors that influence racing are not only relative to the force generating capacities or muscular contractions, but the reduction of friction, aerodynamic drag and overall ground reaction force. Careful consideration is necessary when analyzing alpine skiing movement, as variation is apparent throughout each discipline.

Physiological Assessment

Energy system contribution during alpine skiing is an ongoing debate among sports scientists and coaches alike. Data presented within the research provide an inconsistent interpretation of energy distribution required for racing. This is due to varying metabolic demands across racing disciplines, as well as variance between elite level and recreationally trained athletes. Research suggests that downhill skiing is ~46% aerobic, ~26% glycolytic, and ~28% phosphagenic, while technical skiing is ~30-35% aerobic, ~40% glycolytic, and 25-30% phosphagenic (4, 12, 15, 27, 32, 34, 35). This information provides a generally accepted guideline for the way in which performance is affected during racing. Elite skiers tend to have higher lactate values than non-elite or novice skiers, and have higher repeated force generating capacities (24, 34). Additionally, elite skiers frequently reach values of 80-90% VO_{2max} whereas less skilled skiers rarely reach values above 60-70% VO_{2max} (35). In addition elite DH and SG skiers travel at speeds of nearly 160 km/h during racing (32). Lactate buffering capacity appears to be of utmost importance, while the optimal range for aerobic capacity is uncertain. One could argue that aerobic capacity is critical for recovery during training, which can last for several hours and require multiple (anywhere from 4-14) runs, thus allowing for increased training capacity that ultimately contributes to the highly technical skill aspect of the sport (22, 26, 33). It can be concluded that energy system requirements are specific to both the discipline and skill level of the racing athlete, which should heavily influence coaching and testing approaches. The primary goal of training is to increase the athlete's ability to withstand high levels of accumulated metabolic by-products so that force generating capabilities and neuromuscular coordination are less affected (9).

Postural control and balance during skiing require activation of large muscle groups, particularly the quadriceps. Hintermeister et al. (14) conducted an EMG activity analysis on both U.S. and British national team member skiers, finding that pattern of greatest quadriceps activity occurs during the latter part of the turning phase and early carving phase, which subsequently is the point where the greatest forces are placed on the skier. The tibialis anterior was also shown to be greatly activated as it produced the dorsiflexion needed to put the skier in a forward angle towards the tip of the skis (14). Additional muscle groups that are heavily relied upon are the rectus abdominus, transverse abdominus, external obliques, adductors, erector spinae, and gastrocnemius. The hamstrings and gluteals display high levels of eccentric muscle action in order to absorb the forces encountered on the variable terrain (13, 15, 29). High levels of muscle co-contraction are seen at various stages during a run, supporting balance and posture (14, 21).

Injury Analysis

Due to the high velocities, forces, and variable terrain encountered in alpine skiing, an inherent risk is present within racing. In World Cup alpine ski racing, the most commonly injured body parts are the knees (36%), lower leg (12%), and shoulders (11%), (5, 28). The majority of knee injuries that do occur are from knee extension, or full dynamic knee flexion paired with an anterior draw of the tibia or internal/external rotation (5). The terminology often used to describe these non-contact knee injuries includes “slip catch” (outside ski coming off the ground initiating a carved turn across the body while fully extended), “dynamic snowplow” (abnormal knee and hip flexion from a ski catching an edge while turning under the skier producing forceful internal rotation) and “back weighted landing” (tibiofemoral compression combined with internal or external rotation after an awkward landing of the ski tail hitting the ground and tibial anterior draw) (5, 15). Surprisingly, only a small fraction of the knee injuries reported come from crashing or becoming entangled in netting (5). In contrast, the primary mechanism for shoulder injuries is the occurrence of a crash with an outstretched arm or direct blow to the shoulder complex resulting in rotator cuff strains, anterior glenohumeral dislocations or subluxations, and clavicle fractures (17).

Kokmeyer et al. (18) conducted an analysis on the prevalence of injuries in World Cup Ski Racing, finding that 9.8 injuries occurred for every 1000 runs taken, 38% of which were to the knee. This same study also found that there was a 280% increase in injuries reported between 1981 and 1994. One could argue that the increased technologic advancement of equipment (boots, bindings, skis) contributes greatly to the increased injury rates as they allow for different distributions of torque to the knee (18). It has been proposed that longer skis with a reduced profile, width, and shape may reduce the risk of injury, however this comes at the cost of performance because it reduces the speed and edge angles one can create (28). Additional factors that contribute to injury risk are insufficient core strength/core strength imbalance, gender, skill level, and genetic disposition (28). Performance deficiencies must be addressed through the practice of high-quality strength training in addition to volume controlled on hill training that is intelligently structured. Despite the addition of these factors and high levels of preparation, athletes still remain at risk for injury during competition due to the biomechanistic nature of the sport.

Assessments of the Athlete

In order to successfully implement performance testing, a battery of tests that are reliable, valid, relevant to the sport, and highly repeatable are key (31). It is the author’s belief that five specific tests provide the most comprehensive approach to performance tracking. The order in which they should be completed is as follows, preferably split between two training days: 1) The Star Excursion Balance Test, 2) Counter Movement Jump, 3) Isometric Squat, 4) 2.5 minute loaded repeated jump test (LRJT), and 5) Maximum 20m Shuttle test. It is important to complete these tests in this specific order because fatigue created from one test may negatively impact the performance of another. This series assesses neuromuscular coordination, power, strength, anaerobic endurance, and aerobic capacity respectively.

Star Excursion Balance Test: Neuromuscular coordination is a critical aspect commonly neglected in sports performance, specifically during testing. Filipia et al. (11) suggest the star excursion balance test (SEBT) as a functional screening tool to assess the dynamic stability, motor control, and risk of lower extremity injury in athletes. The test requires participants to balance on one leg while reaching the most distal portion of their opposite limb to the anterior, posteromedial, and posterolateral directions, while remaining upright with the opposite limb stance (11). This test could be used to assess whether the currently implemented strength and conditioning program is addressing neuromuscular coordination, lower extremity strength, and core stability by the change in athlete performance.

López-Plaza et al. (20) found moderate to high reliability in the SEBT when conducted on a group of 27 physically active men, with an intraclass correlation of 0.87 for the dominant leg and 0.74 for the nondominant leg. These results support that the SEBT is a reliable and highly reproducible means for assessing change in postural control and neuromuscular coordination in athletic populations (20), which is important to the success of a high performing and healthy career in alpine ski racing (23).

Counter Movement Jump test: Jordan et al. (16) contend that the countermovement jump (CMJ) is a highly beneficial tool to assess functional asymmetry as well as power and rate of force development in phase specific kinetic impulses of the jump via force plate analysis. Specific attention should be drawn toward the between limb asymmetry through analyzing a CMJ force-time curve (fig. 2) and calculating the asymmetry index as: (left limb impulse - right limb impulse) / (maximum of right and left impulse) x 100.

Figure 2: Force-time tracing of a countermovement jump with the solid and dashed lines representing opposing lower limbs, adapted from (16).

In a study by Jordan et al. (16), it was shown that ACL reconstructed ski racers displayed greater asymmetrical index compared with uninjured ski racers during the concentric phase of the counter movement jump ($p<0.05$) and in phase 2 of the static jump ($p<0.05$). The exact concentric and eccentric forces an athlete produces or lands with can be captured through a countermovement jump making it useful for improving strength and power necessary for skiing performance. If an athlete presents an abnormal or asymmetrical movement, it can be easily targeted and corrected so that the incidence of injury may be reduced during performance (16). In combination with slow motion video analysis, this test captures an array of kinetic qualities, power and force production, as well as functional asymmetry that can easily be tracked over time.

Isometric Back Squat: Alpine skiing requires high levels of isometric and eccentric muscle actions to both change direction and maintain posture throughout a course, thus, assessing the force capabilities of each athlete is critical (15). The isometric squat is a preferable means of assessment over the 1-RM back squat because of its high test-retest reliability and simple means of administration (7). Furthermore, it provides a more applicable means of assessing the isometric contractions commonly seen in alpine skiing over the dynamic concentric contractions in a 1-RM back squat. Blazevich et al. (7) conducted a research study to assess the reliability and validity of the isometric squat, concluding that the reliability was very high with an interclass correlation of 0.97, as well as a strong relation between subject scores in isometric tests and the 1-RM squat tests ($r_{squat} = 0.77$; $p < 0.01$). Validity in relation to the 1-RM back squat was found to be moderate ($r<0.8$), likely due to the low number of test subjects ($n=14$), however this test is still effective at measuring overall force production (7). Given the high reliability and moderate validity of the isometric squat test, it could be used to assess changes in lower body strength before and after training interventions, which is an essential component of alpine skiing performance (9, 10, 18, 22, 27, 29, 32, 34).

2.5 Minute LRJT: Adequate anaerobic capacity and the ability to maintain muscular power are important factors that contribute to the success of alpine ski racers (24). Traditionally, 60 second and 90 second box jump tests have been used to assess the their performance (1, 12, 15, 24, 33). Although decades of data have been collected using these methods, their relation to specific muscle actions seen during skiing are unclear. Continuous box jump tests assess efficiency of stretch-shortening cycle activity or explosiveness, whereas alpine skiing encompasses a series of slow eccentric and concentric muscle contractions (6, 24). The 2.5 minute Loaded Repeated Jump Test provides a more applicable measure of assessing anaerobic capacity and maintenance of muscular power through specific muscle actions seen during ski racing. This test uses 60 loaded countermovement jumps with a load equivalent to 40% of the athlete's body weight through a barbell resting on the back similar to a back squat. A pause between jumps during the LRJT more directly reflects actions seen during skiing compared to continuous jump tests, similar to that of a turn rhythm during a race (SL 1-1.5 s, GS 1.5-2 s, SG 2.4-3 s) compared to continuous explosive jumping tests. Furthermore, the LRJT uses 60 jumps similar to that of the number of gates seen in a SL or GS course, as well as 2.5 minutes being the upper threshold for the duration of a course during a downhill event, making it versatile enough for all disciplines (24). Conversely, the 60 second and 90 second box jump tests provide no data on mean power, nor do they last long enough to parallel the length of a DH race. An original research studied conducted by Patterson et al. (24) showed a high degree of reliability in a test-retest trial of the LRJT with a 95% confidence interval and interclass correlation of 0.987 supporting its efficacy.

Max 20m Shuttle Run Test: The aerobic system comprises approximately 30-46% of the energy contribution to alpine ski racing, thus it is important to assess this aspect of athlete fitness (15). Veicsteinas et al. (35) state that elite level skiers have an approximately 20-30% higher VO_{2max} than matched controls in their research study, suggesting that a high VO_{2max} is beneficial for performance. Increasing aerobic capacity may allow an athlete to recover between training runs at a faster rate and ultimately yield greater training volume. A sound method by which to assess an individual's VO_{2max} is the maximal multistage 20 m shuttle run (MST) (19). Administration of the MST allows multiple athletes to be tested at once while providing accurate results, proving advantageous in club and collegiate level settings where there is not enough time allotted for a traditional test of running to exhaustion via treadmill (3). Aziz et al. (3) conducted a research study examining 8 female National level U18 soccer players who participated in both a MST as well as treadmill run test (TRT). A statistically significant correlation in performance ($p<0.05$) was found between both tests, suggesting that the MST is a valid field-based test for measuring maximal aerobic capacity in athletic populations.

Conclusion:

Based upon the unique nature of alpine ski racing, a specific battery of tests is required to capture the physiological changes necessary for performance. The relatively slow eccentric and concentric muscle actions paired with high levels of neuromuscular coordination place demands on the athlete that must be carefully evaluated for success. Additionally, lower body dexterity, core strength, anaerobic endurance, aerobic capacity, and force generating capacity must all be considered when analyzing the sport. Identifying and monitoring these qualities through appropriate testing ensures that the provided strength and conditioning programs are effective in producing the desired adaptions. While further research is necessary to understand overall demands alpine ski racing places on the human body, the battery of tests summarized herein are effective tools for analyzing performance changes in alpine ski racing.

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