Training-related changes in force-power profiles: implications for the skeleton start

Original Investigation

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Abstract

Purpose: Athletes' force-power characteristics influence sled velocity during the skeleton start, which is a crucial determinant of performance. This study characterised force-power profile changes across an 18-month period and investigated the associations between these changes and start performance. **Methods:** Seven elite- and five talent-squad skeleton athletes' (representing 80% of registered athletes in the country) force-power profiles and dry-land push-track performances were assessed at multiple time-points over two 6-month training periods and one 5-month competition season. Force-power profiles were evaluated using an incremental leg-press test (Keiser A420) and 15-m sled velocity was recorded using photocells. **Results:** Across the initial maximum strength development phases, increases in maximum force (F_{max}) and decreases in maximum velocity (V_{max}) were typically observed. These changes were greater for talent (23.6 and -12.5%, respectively) compared with elite (6.1 and -7.6%, respectively) athletes. Conversely, decreases in F_{max} (elite: -6.7%; talent: -10.3%) and increases in V_{max} (elite: 8.1%; talent: 7.7%) were observed across the winter period, regardless of whether athletes were competing (elite) or accumulating sliding experience (talent). When the training emphasis shifted towards higher-velocity, sprint-based exercises in the second training season, force-power profiles seemed to become more velocity-oriented (higher V_{max} and more negative force-velocity gradient) which was associated with greater improvements in sled velocity (r = 0.42 and -0.45, respectively). **Conclusions:** These unique findings demonstrate the scope to influence force-power generating capabilities in well-trained skeleton athletes across different training phases. In order to enhance start performance, it seems important to place particular emphasis on increasing maximum muscle contraction velocity.

Key words: athletes, ice-track, leg-press, neuromuscular adaptation

Introduction

It is well established that success in sprint-based activities is greatly influenced by an athlete's ability to produce high power output.[1,2] This also applies to the winter Olympic sport of skeleton, as lower-limb power is a key determinant of a fast push-start,[3,4] which is considered to be crucial for overall success in competition.[5] Consequently, skeleton athletes typically dedicate the summer months to developing strength and power through a combination of resistance, sprint and dry-land push-track training. In fact, it has previously been shown that a 14-month period of skeleton-specific intensified training, focussed on developing these physical characteristics, can successfully progress a novice skeleton athlete into a Winter Olympian.[6]

The generation of muscular power is, however, a product of contraction force and velocity and it is possible for different athletes to achieve the same power output with varying contributions of force and velocity.[7] The simultaneous evaluation of force, velocity and power during muscular efforts can, therefore, provide insight into the mechanical determinants and limits of neuromuscular function[7,8] and highlight ways to enhance performance across different sports with unique qualities.[9] Power-generating capabilities are now frequently inferred from force-velocity and force-power relationships, and have typically been captured by either measuring squat-jump heights across a range of resistances[9] or by measuring horizontal ground reaction forces at different horizontal velocities during sprint accelerations.[2,8]

During multi-joint movements, such as leg-extension exercise, the relationship between force production and contraction velocity is quasi-linear[10] and consequently, a parabolic relationship exists between the force and power generated. The negative linear force-velocity relationship has been extrapolated to the axes to yield theoretical maximum force and theoretical maximum velocity, and maximum power has been derived from the vertex of the force-power curve.[2,7-9,11] Each of these theoretical parameters relates to a mechanical limit of the neuromuscular system and therefore has the potential to be a valuable tool with which to monitor athlete development across time and to inform training practices.

Force-power generating capabilities during incremental leg-press exercise have previously been analysed in skeleton athletes in an attempt to identify key physical determinants of performance, with high maximum power output (the peak of the resultant force-power profile) revealed as an important attribute for skeleton athletes to possess.[4] Interestingly, the orientations of calculated linear force-velocity profiles also seem to differentiate start abilities, with more velocity-oriented profiles associated with faster sled velocities.[4] Due to the cross-sectional nature of these previous findings, the effect of training-induced changes in force-power characteristics on an athlete's ability to perform a fast skeleton start is yet to be established. Moreover, longitudinal observations of elite athletes' training effects and the influence on performance are generally sparse in the literature. Knowledge of the scope, nature and typical timeframe of these force-power adaptations to different training stimuli, along with the influence of these changes on start performance, could be potentially valuable to coaches and sports scientists attempting to maximise skeleton athlete development while also providing further understanding regarding neuromuscular adaptations to training. The aims of this study were, therefore, to quantify changes in the force-power profile in well-trained skeleton athletes' across an 18-month period, which included both training and competition seasons, and to investigate the implications of such changes for start performance.

Methods

Participants

Twelve national-squad (seven elite, five talent) skeleton athletes participated in this study (Table 1) representing 80% of the whole athlete population in the country at the time. The female talent-squad athlete's descriptive characteristics are not provided as these would make her identifiable from the data provided. The elite-squad included six athletes who had competed in multiple World Cup and/or World Championship races (two medalled at least once) and one athlete who had medalled in multiple European Cup (developmental level) races. Additionally, two of the athletes competed in the Winter Olympics during the competition season that immediately followed this study period. Talent-squad athletes had recently been identified through a national talent search programme and were preparing for their first season on the developmental level competition circuit. A local research ethics committee provided approval for this study and athletes provided informed consent prior to data collection. The study was conducted in accordance with the Declaration of Helsinki.[12]

****Insert Table 1 about here****

Study design

Force-power characteristics and dry-land push-start abilities we monitored for 18 months (Figure 1). This period consisted of a six-month dry-land training season, a five-month period on ice (competition or sliding practice, depending on the squad), a four-week off-season period of reduced training load, and a second six-month dry-land training season. Athletes' force-power characteristics were assessed on eight (elite) or seven (talent) occasions across this period, which is depicted in Figure 1 alongside the emphases of each training block. Additionally, an overview of the types of exercises and loads involved across these training blocks is provided in Table 2. Start performance was assessed at the beginning and end of each summer training season.

****Insert Figure 1 about here****

****Insert Table 2 about here****

Force-power data collection and processing

Force-power characteristics were assessed using a Keiser A420 horizontal leg-press dynamometer (Keiser Sport, Fresno, CA), which uses pneumatic resistance and measures force and velocity (at 400 Hz) across each effort. Before the first testing day, athletes attended a familiarisation session consisting of one 10-repetition test. All talent-squad athletes attended every scheduled testing session. Due to illness or injury, one elite-squad skeleton athlete missed two testing sessions and a different elite athlete missed one session. At each time-point, athletes performed an eight-minute incremental cycle warm-up followed by two warm-up leg-press efforts from a seated position (approximately 90° knee angle). An incremental ten-repetition test was then completed from the same starting position against low resistance in the initial repetitions and reaching an estimated ‘one-repetition maximum’ resistance on the tenth repetition. Athletes were asked to extend both legs with maximum velocity and resistance was increased until failure (the mean ± SD for number of repetitions performed was 10 ± 2).

Peak force, peak velocity and peak power were recorded for each leg across every repetition. The linear regression relationship between peak force and peak velocity was then assessed, as appropriate for this type of exercise.[10] As shown in Figure 2, this linear relationship was extrapolated to the axes (x = 0 and y = 0) to yield theoretical maximum isometric force (F_{max}) and theoretical maximum velocity (V_{max}), and the gradient of this line (FV_{grad}) was also recorded. A second-order polynomial was fitted through the peak force and peak power data. The equation of this polynomial was numerically differentiated and used to calculate theoretical maximum power (P_{max}) and the force at P_{max} (FP_{max}). Mean values were calculated across both legs for all variables and F_{max}, P_{max} and FP_{max} were expressed relative to body mass. Pilot testing involving five talent squad athletes suggested that day-to-day variation (coefficient of variation; two tests within 24hrs) in these Keiser output measures was 2-4%.

****Insert Figure 2 about here****

Start performance assessment

At the beginning and end of each training season, start performance was assessed on an outdoor dry-land push-track. Athletes completed and documented an individual 30-minute warm-up at the first time-point, which was replicated at subsequent testing sessions. Push-track testing consisted of three maximal-effort push-starts with a three-minute recovery between efforts. Photocells (Brower Timing System; Utah, USA; 0.001-s accuracy) were placed 14.5 and 15.5 m from the starting block to provide sled velocity at the 15-m mark. Previously, 15-m sled velocity has been shown to be a reliable measure (typical error of measurement = 0.1 $m \cdot s^{-1}$)[13] and strongly associated with overall start performance on ice-tracks.[14] Mean values were calculated across the three trials for each athlete.

Statistical analysis

The mean and standard deviation values were computed for each force-power profile descriptor at baseline (first testing session) for elite male, elite female and talent male athlete sub-groups. Percentage changes in all output variables (F_{max}, V_{max}, P_{max}, FP_{max} and FV_{grad}) were calculated between consecutive testing sessions for each individual athlete before mean percentage changes and 90% confidence intervals (CI) were calculated for the elite- and talent-squad separately. Each of these measurements were log-transformed before analysis to improve the normality of distributions and were back-transformed after the percentage changes and CI had been computed. As CI indicate the range within which a value is likely to fall, changes in each of the force-power profile descriptors were deemed likely to be true if the 90% CI did not cross zero. This approach was considered most appropriate due to the small sample sizes of the sub-groups. Additionally, percentage changes in 15-m sled velocity and all force-power profile descriptors (F_{max}, V_{max}, P_{max}, FP_{max} and FV_{grad}) were calculated across both six-month training seasons. Pearson correlation coefficients (±90% CI) were then used to assess the relationships between changes in force-power profiles and changes in start performance. A threshold of 0.1 was set as the smallest practically important correlation, through which clear (both positive and negative) and unclear relationships were defined, as previously recommended.[15]

Results

The greatest inter-squad differences in force-power profile descriptors achieved at baseline appeared to be for theoretical maximum velocity (V_{max}), with elite-squad athletes generally exhibiting higher V_{max} and a more velocity-oriented force-power profile (i.e. lower FP_{max} and more negative FV_{grad}) compared with talent-squad athletes (Table 3). Sled velocity at 15 m was generally higher in the elite compared with the talent squad.

****Insert Table 3 about here****

The percent changes in all force-power variables exhibited by elite- and talent-squad athletes across the specific training blocks are provided in Tables 4 and 5, respectively. Force-power profile changes were considered to be clear if the confidence intervals did not cross zero. Increases in F_{max} and decreases in V_{max} were observed across the initial phase of the first training season (i.e. focussed on maximum strength development) in both the elite- (F_{max}, 6.1%; V_{max}, -7.6%) and talent-squad athletes (F_{max}, 23.6%; V_{max},-12.5%). Consequently, the gradient of the linear force-velocity relationship (FV_{grad}) became less negative (flatter) and the force at maximum power (FP_{max}) shifted rightward towards higher force values. As expected due to differences in training histories, the magnitude of these changes was larger in the talent-squad athletes compared with the elite group. For both squads, there were no clear changes in force-power characteristics across the latter half of the first training season. Conversely, across the winter period, athletes from both squads exhibited V_{max} increases (8.1% for elite and 7.7% for talent athletes) but F_{max} was found to decrease (-6.7% for elite and -10.3% for talent athletes). Thus, FV_{grad} became steeper (more negative) for all athletes (-16.9% for elite and -20.8% for talent athletes). For the elite squad only, the period of reduced training (four weeks between ice-track and dry-land seasons) resulted in decreases in P_{max} (-6.2%) and V_{max} (-3.3%). All changes exhibited by the talent squad across this period were not deemed to be clear (confidence intervals overlapped zero).

****Insert Tables 4 and 5 about here****

No clear changes in force-power characteristics were observed across the initial stages of the second observed training season until the latter training blocks, where decreases in F_{max} and shifts towards more velocity-oriented profiles were typically exhibited by both squads. For example, talent-squad athletes performed lower maximum force and power values (F_{max}, -8.1%; P_{max}, -9.3%) at the end of this period (October), and the FV_{grad} was found to become more negative (-10.2%), compared with the August session. Similar changes were observed in the elite-squad athletes between June and August in year 2, where decreases in both maximum force (F_{max}, -6.7%) and power (P_{max}, -6.3%) were observed, along with a leftward shift in FP_{max} (-7.2%) towards higher velocities.

Mean changes in 15-m sled velocity across the two training seasons (year 1 and year 2) were 2.2% (90% CI: 0.3 to 4.1%) and 1.7% (0.2 to 3.2%), respectively, for the elite squad. Corresponding values were 1.2% (-0.4 to 2.7%) and 0.7% (-2.2 to 3.7%), respectively, for the talent-squad athletes. The only clear associations observed between these improvements in start performance and changes in force-power profiles were in the second training season (Figure 3). Increases in theoretical maximum velocity were associated with greater improvements in start performance (*r* = 0.42; -0.10 to 0.76, 90% CI). Additionally, shifts towards more velocity-oriented force-velocity profiles were associated with faster starts, as greater improvements in start performance were observed when gradients of the force-velocity relationships became steeper (more negative; *r* = -0.45; -0.78 to 0.06, 90% CI).

****Insert Figure 3 about here****

Discussion

Force-power characteristics exhibited during horizontal leg-press exercise have been shown to be associated with skeleton start ability.[4] Thus, understanding the nature and timescale of strength and power development in skeleton athletes, along with the influence of changes on performance, could inform individualised-training prescription and allow more accurate evaluation of athlete development. Over the 18-month period across which this study was conducted, there was clear scope for changes in the force-power profile seemingly in line with the varying training stimuli provided by the summer dry-land training and winter ice-track periods. Increasing leg-press maximum contraction velocity and shifting the force-power profile towards higher velocities were associated with improvements in sled velocity, and thus, warrant consideration when designing training programmes to enhance start performance.

At the beginning of the first training period, elite-squad athletes, who tended to be faster push-starters, recorded higher leg-press theoretical maximum velocity but similar maximum force and power values compared with the talent-squad athletes (Table 3). The importance of high maximum contraction velocity for sprint performance has previously been highlighted by research analysing force-power profiles obtained during sprint acceleration.[2] In this previous work, a strong positive association (*r* = 0.84) was reported between sprint performance (4-s distance) and theoretical maximum horizontal velocity, but a weaker relationship was observed with theoretical maximum horizontal force (*r* = 0.43). Thus, it appears important for both sprint and skeleton athletes' training programmes to be geared towards enhancing the ability to extend the lower limbs rapidly, and not only forcefully. Moreover, it has been suggested that explosive performance is determined by both the maximisation of power and the optimisation of force-velocity characteristics,[7] which may be achieved through individualised programming targeted at specific neuromuscular adaptations. In the current study, elite athletes appeared to exhibit more ‘velocity-oriented’ force-power profiles during leg-press exercise compared with the talent-squad athletes. This supports previous work which has suggested that the orientation of the leg-press force-power profile is also an important determinant of sled velocity with superior starters producing their peak power at faster velocities.[4]

In line with previous studies,[16,17] there was greater scope for adaptive responses when athletes were in less trained states. This is likely due to the well-acknowledged ‘principle of diminished return’, which relates to the influence of initial training status on subsequent adaptation.[18] In the current study, for example, large gains in maximum force production during leg-press exercise were observed in the initial stages of the first training season, especially in the talent athletes (23.6% increase in F_{max}) who had less-extensive training histories than the elite athletes (6.1%). However, this was accompanied by decreases in theoretical maximum velocity and shifts in the force-power profile towards higher forces (increases in FP_{max} were observed in both athlete groups: 7.5% for the elite and 20.1% for the talent). Given that these training blocks were focussed on developing maximum strength (and involved only a small volume of sprint or low-resistance, high-velocity training), these findings also reinforce the load-specific nature of adaptive responses to training.[19,20]

Distinct changes in leg-press force-power profiles were exhibited by both groups of athletes across the winter season, and did not seem to differ markedly between those competing internationally (elite squad) and those accumulating ice-track experience (talent squad). There appeared to be a clear shift in the force-power profiles with increases in theoretical maximum velocity and concomitant reductions in theoretical maximum isometric force (Tables 4 and 5). Consequently, the gradient of the force-velocity relationship was found to become steeper (i.e. more negative; changes were -16.9% for elite and -20.8% for talent athletes) across the winter season. This could be attributed to the typically decreased volume of resistance training undertaken across this period, which could partly be due to a reduction in access to facilities when continuously travelling and partly due to a difference in the training emphasis. In fact, skeleton athletes have been observed to lose considerable lean mass (e.g. decreases ranging from 2-8%) across the winter competition period.[21] Given that a more velocity-oriented force profile appears to be beneficial to skeleton performance[4] and sprint performance,[2] the observed changes may actually be advantageous in skeleton providing that maximum power output does not concurrently decrease (which it did not in this study). Thus, the adaptive responses exhibited across the winter period in this study seem favourable and appear to indicate that start performances peaked for the most important competitions towards the end of the season.

Training consisted of a greater volume of sprint-based exercises in the second training season (April to October year 2) compared with the first, and there was less emphasis on maximum strength development in a deliberate attempt to enhance sprint ability. A reduction in the resistance used in training is likely responsible for the apparent decrease in maximum strength and power capacity. Moreover, athletes exhibited a shift in the leg-press force-power profile towards higher velocities, in line with the load-specific adaptive responses in force-power capabilities previously exhibited in recreational athletes.[19,20] Thus, this study alludes to a similar moderating effect of load on the training responses in well-trained individuals. Importantly, the observed shifts in the force-power profile towards higher velocities appear to be practically meaningful, as these were clearly associated with greater push-start performance improvements (r = -0.45) across the second training season (Figure 3). Furthermore, increasing maximum velocity across this period also appeared to be beneficial to start performance (r = 0.42). However, as peak power concomitantly reduced, which is an important determinant of skeleton start performance,[3,4] the overall force-power profile changes exhibited may not be entirely favourable. This reflects the ongoing challenge for strength and conditioning practitioners to concurrently improve or maintain all relevant physical and physiological determinants of human performance, which is especially difficult when these characteristics are somewhat contradictory in nature. Interestingly, decreases in peak power were not directly associated with reductions in sled velocity (Figure 3) despite the well-established association between these variables when analysed in a cross-sectional manner.[3,4] This highlights the multi-factorial nature of training responses and the difficulty of isolating the effects of different adaptive responses on performance. Other start-performance determinants (e.g. skeleton-specific, technique-based factors) are likely to concomitantly change across the season and influence the sled velocities, but this would clearly not be detected during the leg-press exercise.

It is also unclear why the associations between leg-press force-power profile changes and performance were only observed across the second season (Figure 3) particularly as the changes were, in many cases, smaller compared with the first. However, the increased volume of sprint and push-track sessions could provide a possible explanation. Previously, resistance training-induced increases in lower-limb power have been shown to have little effect on sprint times when power training is conducted in the absence of sprint-specific exercises.[22] It has been suggested that in order for neuromuscular adaptations to translate into sprint-based performance enhancement, sport-specific exercises are necessary to 'convert' neuromuscular adaptations into a coordinated movement.[23,24] Thus, the greater volume of sprinting and push-starting in the second season may have facilitated the transfer of the neuromuscular adaptations into higher sled velocities. Estimating force-velocity-power profiles during sprint running itself,[25] in addition to those during leg-press exercise, could provide some new insight into this potential transfer mechanism.

The physical determinants that contribute to a fast push-start are now well established with start performance predominantly explained by explosive power output, sprint ability and high-velocity lower-limb contractions.[3,4] The novelty of the current study is the demonstration that clear changes in these key physical characteristics are induced across distinct phases of the training cycle and in response to varying training stimuli. Importantly, this study has also shown that some of these neuromuscular adaptations influence start performance and can, therefore, provide important insight to inform individualised training for skeleton athletes. However, the necessary sequence of periodisation to best elicit these responses remains unknown. In well-trained individuals, who have difficulty in achieving substantial gains in strength and power, sophisticated programming is necessary.[17] Harris et al. [22] demonstrated that a block of strength training followed by high velocity, sport-specific training was more beneficial to sprint performance than a block of either high-force or high-power training in university-level American football players. The pattern of periodisation adopted by Harris et al. [22] is similar to that undertaken in the current study with the latter phases of high-velocity training evoking favourable responses in skeleton start performance.

There is, nonetheless, no clear consensus regarding which combination of resistance training elicits the largest gains in sprint-based performances across multiple training mesocycles. This is perhaps partly due to the reluctance of athletes and coaches to adapt training sessions as well as the impracticality of conducting controlled trials in competitive sport settings.[26] Consequently, the majority of training studies to date have been limited to short-term studies (6-12 weeks) involving recreational athletes, where neuromuscular responses are realised without difficulty.[19] More sophisticated training studies conducted in elite training settings would enable practitioners to base training programmes on externally-valid research and not rely on anecdotal evidence. Naturally, it is challenging to capture accurate accounts of the individualised training programmes. Indeed, a limitation of the study is that it was not possible to collect and link the observed adaptive responses to specific training stimuli. Nonetheless, this study does provide some insight into how the force-power profile of athletes can change in response to different training blocks with varying emphases, as well as the potential performance implications of these changes.

Practical Applications

Dry-land training clearly provides opportunity for neuromuscular adaptation and alteration of leg-press force-power qualities in skeleton athletes. However, reducing the resistance load and undertaking greater volumes of sport-specific exercises during certain training phases (whether deliberately programmed during the latter phases of training seasons or as an anticipated, natural outcome of the competition period) can result in seemingly beneficial shifts in the force-power profiles towards higher velocities. This appears to allow skeleton athletes' start performances to peak at a critical phase of the competition cycle.

Conclusions

This study is one of few to document long-term neuromuscular adaptive responses to training in a well-trained population. Notwithstanding the widely accepted 'principle of diminished return', there appeared to be scope for training-specific responses in skeleton athletes' leg-press force-power profiles to be induced by the different stimuli provided by the summer dry-land training and winter ice-track periods. A leftward shift in the force-power profiles (towards higher contraction velocities) and increases in theoretical maximum contraction velocity seemed to have positive implications for start performance and training should be carefully prescribed to target these characteristics. The inclusion of greater volumes of sport-specific exercises in training programmes could potentially facilitate the transfer of force-power profile changes to skeleton start performance.

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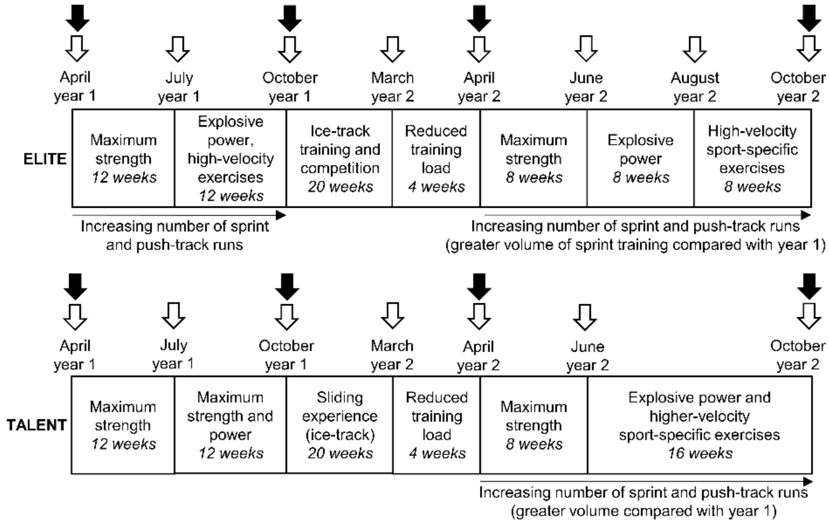

Figure 1. A schematic of the testing schedule in relation to specific training blocks for elite- (top, n = 7) and talent- (bottom, n = 5) squad skeleton athletes. Open and filled block arrows denote timings of the force-power and dry-land push-start testing sessions, respectively.

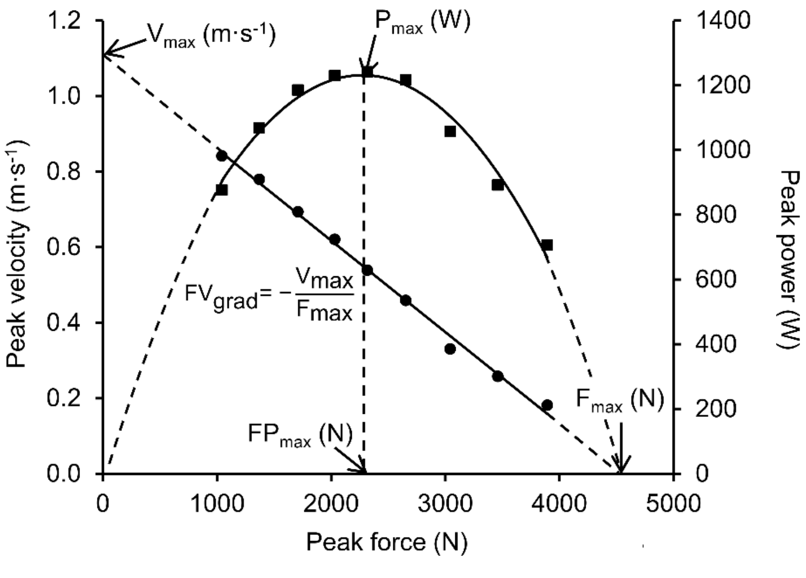

Figure 2. An example of the force-velocity and force-power relationships obtained and the variables calculated from the leg-press testing. Circles and squares indicate raw force-velocity and force-power data, respectively. Solid black lines represent the line of best fit through the raw data. Extended dashed lines represent the data extrapolation to the axes. Vertical dashed line indicates method used to calculate force at maximum power (FP_{max}). F_{max} = theoretical maximum force, V_{max} = theoretical maximum velocity, P_{max} = maximum power, FV_{grad} = gradient of force-velocity relationship.

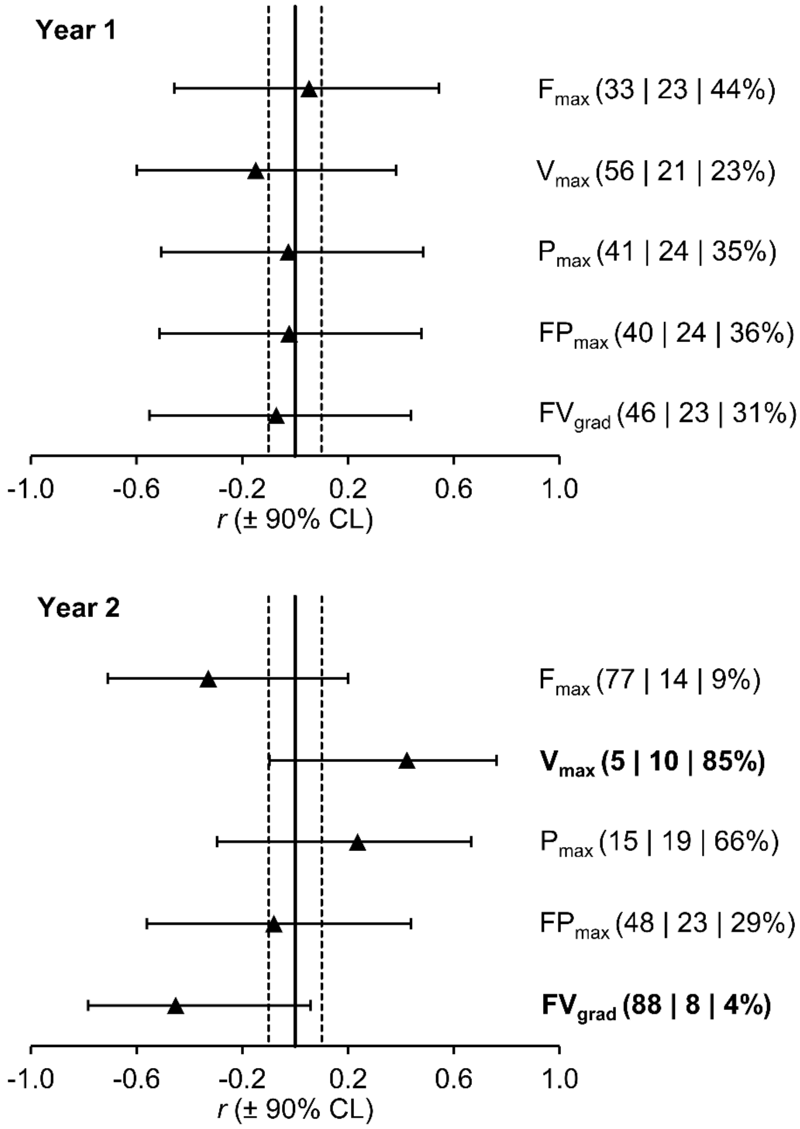

Figure 3. Pearson correlation coefficients (± 90% CI) between changes in force-power profile descriptors and skeleton start performance (15-m sled velocity) changes across the training seasons (year 1 and 2). Central area (r = 0.0 ± 0.1) indicates a trivial relationship. Percentages in brackets represent likelihoods that the effect is negative | trivial | positive. F_{max} = theoretical maximum force, V_{max} = theoretical maximum velocity, P_{max} = maximum power, FP_{max} = force at maximum power, FV_{grad} = gradient of force-velocity relationship. Bold labels indicate relationships which were considered clear.

Table 1. Descriptive characteristics (mean ± SD) for three athlete sub-groups.

	Age (years)	Mass (kg)	Height (m)
Elite male (n = 3)	26 ± 2	84.0 ± 6.9	1.79 ± 0.10
Elite female (n = 4)	24 ± 2	68.3 ± 3.0	1.71 ± 0.02
Talent male (n = 4)	22 ± 1	72.2 ± 4.2	1.73 ± 0.04

Table 2. Typical exercises, loading and repetition schemes adopted across training blocks with specific training emphases

Training emphasis	Session	Exercises	Load	Repetition scheme	Weekly frequency
Maximal strength development	Strength	Deadlift (variations) Leg press Hack squat	80-98% (of 2RM)	6 x 2-5	3
	Supplementary strength	Squat jumps Single leg squats High pulls	50% BW 10-20 kg 40-50 kg	10 x 30 secs	1-2
Explosive power development	Strength-speed	Squat jumps Single leg hops Double leg bounds	40% BW	3-4 x 2-5 2-3 x 8-10 3 x 30 m	3
	Supplementary exercises	Glute hamstring raises Lunge walks		2 x 8 2 x 10	3
Higher-velocity / sport-specific	Speed	Sprints Sled pulls Hurdle jumps	Unloaded 10-20 kg Unloaded	3 x 40 m 3 x 40 m 3 x 5	3
	Supplementary exercises	Reverse lunges Glute hamstring raises		2 x 8-10 2-4 x 6-10	3

N.B. This table provides an overview of the types of training prescribed in blocks with specific training emphases. Athletes followed individualised programmes within this general structure. 2RM = two-repetition maximum. Repetition scheme = sets x reps. BW = body weight

Table 3. Force-power characteristics and 15-m sled velocities (mean ± SD) achieved at baseline (first testing session) by elite- and talent-squad skeleton athletes.

	Elite male (n = 3)	Talent male (n = 4)	Elite female (n = 4)	Talent female (n = 1)
Maximum force (F_{max}, $N \cdot kg^{-1}$)	75.1 ± 5.7	77.4 ± 8.7	63.7 ± 7.0	65.8
Maximum velocity (V_{max}, $m \cdot s^{-1}$)	1.25 ± 0.04	1.10 ± 0.08	1.07 ± 0.18	0.88
Maximum power (P_{max}, $W \cdot kg^{-1}$)	21.1 ± 1.7	20.8 ± 0.9	15.9 ± 1.5	15.1
Force at maximum power (FP_{max}, $N \cdot kg^{-1}$)	37.4 ± 2.4	39.7 ± 5.5	31.0 ± 2.5	35.6
Force-velocity gradient (FV_{grad}, $\cdot 10^4$)	-1.66 ± 0.08	-1.44 ± 0.25	-1.71 ± 0.44	-1.33
Sled velocity at 15 m ($m \cdot s^{-1}$)	7.55 ± 0.17	7.39 ± 0.17	6.75 ± 0.26	6.57

Table 4. Percentage changes (90% confidence intervals) in force-velocity and force-power profile descriptors across each training block (emphases in italics) or competition period in elite-squad skeleton athletes.

	April year 1 - July year 1	**July year 1 - October year 1**	**October year 1 - February year 2**	**February year 2 - April year 2**	**April year 2 - June year 2**	**June year 2 - August year 2**	**August year 2 - October year 2**
	Maximum strength	*Explosive power, high-velocity*	*Ice-track competition*	*Reduced training load*	*Maximum strength*	*Explosive power*	*High-velocity, sport-specific*
Maximum force (F_{max})	**6.1% (0.2 to 12.0%)**	2.1% (-4.0 to 8.2%)	**-6.7% (-11.6 to -1.9%)**	-0.4% (-4.6 to 3.7%)	2.4% (-3.0 to 7.8%)	**-6.7% (-11.4 to -2.1%)**	-3.1% (-6.9 to 0.8%)
Maximum velocity (V_{max})	**-7.6% (-12.2 to -3.0%)**	-4.7% (-10.2 to 0.9%)	**8.1% (4.0 to 12.1%)**	**-6.2% (-11.4 to -0.9%)**	1.7% (-6.9 to 10.3%)	-1.0% (-8.3 to 6.2%)	3.0% (-1.7 to 7.6%)
Maximum power (P_{max})	2.7% (-1.5 to 6.9%)	-0.6% (-4.8 to 3.7%)	-1.5% (-4.1 to 1.2%)	**-3.3 % (-6.2 to -0.4%)**	3.8% (-1.3 to 8.8%)	**-6.3% (-12.5 to -0.1%)**	-1.1% (-5.4 to 3.2%)
Force at maximum power (FP_{max})	**7.5% (0.1 to 15.0%)**	2.9% (-4.2 to 10.0%)	-6.0% (-13.3 to 1.2%)	-2.4% (-5.8 to 1.0%)	2.8% (-1.4 to 7.0%)	**-7.2% (-10.7 to -3.8%)**	-3.3% (-7.5 to 0.9%)
Force-velocity gradient (FV_{grad})	**11.3% (4.6 to 18.0%)**	5.9% (-8.0 to 19.8%)	**-16.9% (-27.8 to -6.0%)**	7.6% (-1.0 to 16.3%)	1.9% (-11.4 to 15.3%)	-4.6% (-16.1 to 6.9%)	-6.0% (-12.6 to 0.6%)

N.B. negative change in the force-velocity gradient indicates relationship has become steeper and is therefore more negative.
Bold results indicate results where confidence intervals do not cross zero, and thus a change in that characteristic was deemed to have occurred.

Table 5. Percentage changes (90% confidence intervals) in force-velocity and force-power profile descriptors across each training block (emphases in italics) or ice-track sliding period in talent-squad skeleton athletes.

	April year 1 - July year 1 *Maximum strength*	**July year 1 - October year 1** *Explosive power, high-velocity*	**October year 1 - February year 2** *Ice-track competition*	**February year 2 - April year 2** *Reduced training load*	**April year 2 - June year 2** *Maximum strength*	**June year 2 - October year 2** *Explosive power, high-velocity*
Maximum force (F_{max})	**23.6% (13.4 to 29.4%)**	2.3% (-2.7 to 7.3%)	**-10.3% (-16.6 to -4.1%)**	5.6% (-3.2 to 14.3%)	-1.3% (-5.7 to 3.1%)	**-8.1% (-15.3 to -0.8%)**
Maximum velocity (V_{max})	**-12.5% (-23.2 to -1.8%)**	0.1% (-7.4 to 7.6%)	**7.7% (3.4 to 12.1%)**	-2.7% (-8.8 to 3.3%)	-1.8% (-9.0 to 5.4%)	2.3% (-2.5 to 7.1%)
Maximum power (P_{max})	1.5% (-7.7 to 10.6%)	2.6% (-1.5 to 6.7%)	0.7% (-4.3 to 5.6%)	1.4% (-4.1 to 6.8%)	-1.9% (-7.4 to 3.5%)	**-9.3% (-14.9 to -3.7%)**
Force at maximum power (FP_{max})	**20.1% (8.3 to 31.9%)**	2.4% (-3.6 to 10.4%)	-5.4% (-11.6 to 0.9%)	-0.3% (-11.1 to 10.6%)	-1.7% (-7.3 to 3.9%)	-0.9% (-9.0 to 7.2%)
Force-velocity gradient (FV_{grad})	**28.6% (9.0 to 48.2%)**	2.8% (-10.4 to 16.1%)	**-20.8% (-29.2 to 12.4%)**	7.5% (-6.2 to 21.2%)	2.9% (-8.3 to 14.1%)	**-10.2% (-19.6 to -0.9%)**

N.B. negative change in the force-velocity gradient indicates relationship has become steeper and is therefore more negative.
Bold results indicate results where confidence intervals do not cross zero, and thus a change in that characteristic was deemed to have occurred.