



Citation for published version:

Colyer, SL, Stokes, KA, Bilzon, JLJ, Holdcroft, D & Salo, AIT 2018, 'The effect of altering loading distance on skeleton start performance: Is higher pre-load velocity always beneficial?', *Journal of Sports Sciences*, vol. 36, no. 17, pp. 1930-1936. <https://doi.org/10.1080/02640414.2018.1426352>

DOI:

[10.1080/02640414.2018.1426352](https://doi.org/10.1080/02640414.2018.1426352)

Publication date:

2018

Document Version

Peer reviewed version

[Link to publication](#)

This is an accepted manuscript of an article published by Taylor and Francis in *Sports Performance* on 16/01/2018, available online <http://www.tandfonline.com/10.1080/02640414.2018.1426352>

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The effect of altering loading distance on skeleton start performance: Is higher pre-load velocity always beneficial?

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Running title: Altering loading distance of the skeleton start

Key words: athletes, experimental, ice-track, intervention, sled velocity.

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Acknowledgements

The authors thank all athletes who were involved in this study for their participation and cooperation. Aspects of this research were funded by the United Kingdom Sports Council, British Skeleton Ltd., the University of Bath, and CAMERA, the RCUK Centre for the Analysis of Motion, Entertainment Research and Applications, EP/M023281/1 (@CAMERA_Bath)

Abstract

Athletes initiating skeleton runs differ in the number of steps taken before loading the sled. We aimed to understand how experimentally modifying loading distance influenced sled velocity and overall start performance. Ten athletes (five elite, five talent; 67% of all national athletes) underwent two to four sessions, consisting of two dry-land push-starts in each of three conditions (preferred, long and short loading distances). A magnet encoder on the sled wheel provided velocity profiles and the overall performance measure (sled acceleration index). Longer pre-load distances (12% average increase from preferred to long distances) were related to higher pre-load velocity ($r = 0.94$), but lower load effectiveness ($r = -0.75$; average reduction 29%). Performance evaluations across conditions revealed that elite athletes' preferred distance push-starts were typically superior to the other conditions. Short loading distances were generally detrimental, whereas pushing the sled further improved some talent-squad athletes' performance. Thus, an important trade-off between generating high pre-load velocity and loading effectively was revealed, which coaches should consider when encouraging athletes to load later. This novel intervention study conducted within a real-world training setting has demonstrated the scope to enhance push-start performance by altering loading distance, particularly in developing athletes with less extensive training experience.

Introduction

In the winter sport of skeleton, athletes begin every run by explosively pushing the sled with a bent-over posture for approximately 25-30 m, before propelling themselves forward to load the sled and adopt a prone driving position. Individual start strategies have previously been documented for elite female skeleton athletes during ice-track competitions with differences reported in the number of steps and time taken to load the sled (Bullock et al., 2008). This individuality presumably reflects athletes' efforts to achieve the fastest start possible in order to improve overall chances of success (Zanoletti, La Torre, Merati, Rampinini, & Impellizzeri, 2006). Sprint acceleration and lower limb power are amongst the physical characteristics known to influence overall start performance in skeleton (Colyer, Stokes, Bilzon, Cardinale, & Salo, 2017; Sands et al., 2005). Moreover, sprint and jump ability have been positively associated with both the distance and velocity of the sled when the athlete loads, suggesting that physical capacity could be a key factor influencing the loading strategy adopted (Colyer, Stokes, Bilzon, & Salo, 2017).

As previously demonstrated, a skeleton athlete should strive to maximise pre-load velocity and load the sled when the velocity increments due to the influence of gravity surpass the acceleration produced by the athlete (Colyer, Stokes, Bilzon, & Salo, 2017). Thus, athletes are typically encouraged to increase the number of ground contacts before loading in order to attain the highest pre-load velocity possible. In fact, it has been shown that the fastest starters in two international women's races were those who took a greater number of steps (Bullock et al., 2008). This, however, assumes that the ability to load the sled effectively is not influenced by pre-load velocity, an interaction which is yet to be investigated. As a fast start is considered to

be a prerequisite for overall success in skeleton (Zanoletti et al., 2006), it is important to assess the relationships between pre-load conditions (velocity and distance) and the success of the loading phase, and to investigate the potential scope to improve skeleton start performance by adapting loading distance. The aims of this study were, therefore, to understand the effect of altering the distance at which an athlete loads the sled and to assess whether start performance is enhanced by experimentally modifying loading distance. The main hypothesis was that increased pre-load distance and velocity would improve skeleton start performance.

Methods

Ten (one male and four female elite-squad, and four male and one female talent-squad) skeleton athletes participated in this study. These athletes represented two thirds of the available competitive skeleton athlete population in the country. The mean (\pm SD) age, mass and height of the male participants was 23 ± 2 years, 75.2 ± 7.3 kg and 1.73 ± 0.06 m, respectively, and 24 ± 2 years, 66.0 ± 5.7 kg and 1.68 ± 0.06 m, respectively, for the female participants. A local research ethics committee provided ethical approval for this research to be conducted and all athletes provided written consent.

Data collection sessions took place weekly (between 0930 and 1130 hours) across a six-week period of summer training with athletes attending an average of three sessions (range 2-4 sessions). During each testing session, participants performed a total of six maximal-effort push-starts, two in each of the three conditions: preferred, long and short distance push-starts. These conditions related to how far athletes perceived they were running before loading the sled. Athletes were simply instructed to under-run and over-run their preferred distance in the short and long conditions,

respectively. Following an athlete-led warm-up, athletes first performed two preferred distance push-starts at each testing session to provide a standard reference with which long and short push-starts were compared in order to account for any potential training effect. The order of the remaining two conditions was randomised to avoid sequencing effects and a recovery period of at least three minutes was taken between efforts. Three athletes attended two testing sessions, five attended three sessions and two attended four sessions, resulting in four, six and eight trials in each condition, for the respective athletes.

Push-starts were performed by pushing a wheeled sled that ran along metal rails embedded in the surface of an outdoor dry-land push-track. One of the sled wheels was instrumented with a custom-built magnet encoder (Sleed, Sheffield Hallam University, United Kingdom), which provided the time interval for each complete turn of the wheel (every 0.1984 m), as described previously (Colyer, Stokes, Bilzon, & Salo, 2017). A Sony HC9 video camera (50 Hz at 1/600 s shutter speed) was located next to the track approximately 10 m from the starting block and panned to capture the entire start phase. The number of steps taken before loading was subsequently recorded from the video footage for each push-start.

Raw sled velocity data were exported from the Sleed software and velocity-distance profiles were plotted for each trial. Exactly the same data processing methods were adopted as in a previous study (Colyer, Stokes, Bilzon, & Salo, 2017). The pre-load time-point was defined as the final data point before a decrease in velocity (indicative of the end of the initial acceleration phase and the start of the loading phase; Figure 1). The first data point after the load following which the increase in velocity was

approximately constant (i.e., no further propulsion from the athlete) was defined as the post-load time-point. A sixth-order polynomial was fitted from the start of the velocity data to ten points after the pre-load time-point. Additionally, a linear trendline was fitted to the post-load data. Velocity drop during the load was defined as the greatest negative velocity change across the loading phase compared with the pre-load time-point (Figure 1). Load effectiveness was calculated by extrapolating the post-load linear trendline to the pre-load time-point and computing the difference between this extrapolated velocity and the actual pre-load velocity. A sled acceleration index (Colyer, Stokes, Bilzon, & Salo, 2017) was used to evaluate start performance level using the following equation:

$$\text{Sled acceleration index} = \frac{55 \text{ m velocity}}{15\text{-}55 \text{ m time}}$$

[Figure 1 near here]

Means and standard deviations were calculated for each of the following start performance descriptors for each athlete across all trials in each condition (preferred, short and long loading distance): number of steps, pre-load velocity, pre-load distance, velocity drop and load effectiveness. Standardised differences (effect sizes) were used to assess for differences in these start performance descriptors between the three loading conditions. The within-athlete relationships between pre-load conditions (velocity and distance) and loading variables (velocity drop and load effectiveness) were assessed for each individual athlete using Pearson correlation coefficients. Individual coefficients were then combined via Fisher transformation using an online spreadsheet (Hopkins, 2006b) to provide combined group correlations (\pm 90% CI) and magnitude-based inferences. A threshold of 0.1 was set for the smallest practically

important correlation, through which clear and unclear relationships were defined. A relationship was considered positive only if the r value was greater than +0.1 and the lower CI did not cross -0.1, and negative if the r value was less than -0.1 and the upper CI did not extend past +0.1. If the CI crossed over both +0.1 and -0.1, relationships were considered unclear.

Standardised differences (effect sizes) were also calculated to assess the effect of adopting differing loading strategies on overall start performance (sled acceleration index) for individual athletes. Sample size estimation for this analysis was conducted using a published spreadsheet (Hopkins, 2006c), which revealed that a minimum sample size of 5 trials per athlete, per condition was required to achieve adequate statistical power. This relates to a 5% chance of type I and type II errors, as recommended for this type of analysis (Hopkins, 2006a). An insufficient number of trials were available for two elite-squad and one talent-squad athlete and so this part of the study was possible for seven (three elite- and four talent-squad) athletes only. For all effect sizes calculated in this study, a smallest worthwhile effect of 0.2 was set through which clear and unclear effects were defined in the same way as for the correlation coefficients.

Results

The number of steps, pre-load velocity and pre-load distance were all substantially higher in the long vs. preferred condition (effect size \pm 90% CI = 1.26 ± 0.37 , 0.60 ± 0.18 and 1.34 ± 0.39 , respectively) and in the preferred vs. short condition (effect size = 1.25 ± 0.36 , 0.64 ± 0.19 and 1.24 ± 0.36 , respectively), as shown in Table 1. For example, when athletes increased the pre-load distance by 2.97 m through taking 1.5

more steps (average difference between the preferred to long conditions), pre-load velocity was also found to be $0.37 \text{ m}\cdot\text{s}^{-1}$ higher. However, velocity drop during the loading phase was also substantially greater during both the long and preferred distance push-starts compared with the short (effect size \pm 90% CI = 0.99 ± 0.43 and 0.66 ± 0.26 , respectively). Additionally, substantially higher load effectiveness (which corresponds to the velocity increase across the loading phase above that due to the constant gravitational acceleration component) was reported in the short vs. preferred (effect size \pm 90% CI = 0.53 ± 0.26), preferred vs. long (0.95 ± 0.13) and the short vs. long (1.36 ± 0.18) conditions. Thus, when pre-load velocity increased by $0.37 \text{ m}\cdot\text{s}^{-1}$ (longer vs. preferred distance push-starts; loading distance was increased by 2.97 m), the effectiveness of the loading phase was found to be $0.16 \text{ m}\cdot\text{s}^{-1}$ lower. However, no overall differences in start performance (the sled acceleration index) between the three loading distance conditions were observed at a group level (effect sizes \pm 90% CI ranged from -0.17 ± 0.07 to -0.09 ± 0.09).

[Table 1 near here]

Several of the combined within-athlete correlations between start performance descriptors (pre-load distance, pre-load velocity, velocity drop and load effectiveness) reflected clear relationships (Figure 2). For all 10 athletes, longer pre-load distances were associated with higher pre-load velocities ($r = 0.94$, 90% CI = 0.92 to 0.96). However, higher pre-load distances were also associated with lower load effectiveness ($r = -0.75$, 90% CI = -0.81 to -0.68), and similarly, a negative relationship was observed between pre-load velocity and load effectiveness ($r = -0.87$, -0.90 to -0.83). Likewise, both pre-load velocity ($r = 0.52$, 90% CI = 0.40 to 0.62) and pre-load

distance ($r = 0.35, 0.21$ to 0.47) were associated with a greater velocity drop during the loading phase, which in itself was associated with lower load effectiveness ($r = -0.55, -0.64$ to -0.43).

[Figure 2 near here]

When the analysis was conducted at the individual-athlete level, differences in the sled acceleration index were exhibited across conditions for certain athletes (Figure 3). Five out of seven athletes achieved a higher sled acceleration index when loading at their preferred compared with short distances. Additionally, three out of seven athletes performed a superior start in the preferred vs. long condition. However, running further before loading the sled seemed to be beneficial for some talent athletes. For example, the sled acceleration index for athlete T1 was found to be higher in the long loading distance condition compared with their preferred (effect size $\pm 90\%$ CI = 0.87 ± 1.03). On the other hand, short distance push-starts resulted in superior start performance compared with the long distance push-starts for athlete T4 (effect size $\pm 90\%$ CI = 0.35 ± 0.45).

[Figure 3 near here]

Discussion

The primary purpose of this study was to understand the influence of experimentally altering loading distance on the sled velocity profile and indices of overall skeleton start performance. When individual athletes increased their pre-load distances, higher pre-load velocities were also achieved. However, a negative interaction between pre-

load velocity and the success of the loading phase was also observed, which influenced the overall effect of increasing loading distance on start performance. Consequently, in contrast to the main hypothesis, maximising pre-load velocity did not always result in better overall skeleton start. There were important between-athlete differences in the loading distance condition that resulted in individuals' highest levels of overall start performance.

Pre-load conditions (distance and velocity) and the loading phase have previously been found to independently contribute to the start phase with higher pre-load velocities and greater load effectiveness associated with faster starts (Colyer, Stokes, Bilzon, & Salo, 2017). However, it is conceivable that a change in the pre-load conditions may influence the subsequent loading phase. Indeed, higher pre-load velocities and distances were associated with greater velocity drops (combined $r = 0.52$ and 0.35 , respectively) and less effective loading phases (combined $r = -0.87$ and -0.75 , respectively) across all 10 athletes involved in this research (Figure 2). For context, when athletes increased pre-load velocity by 5% from 8.15 to $8.53 \text{ m}\cdot\text{s}^{-1}$ (when loading distance was increased by 12% from 25.6 to 28.6 m), the velocity drop during the load increased by 14% from 0.36 to $0.41 \text{ m}\cdot\text{s}^{-1}$ and the effectiveness of the loading phase exhibited a 29% decrease from 0.55 to $0.39 \text{ m}\cdot\text{s}^{-1}$ (Table 1). As such, this study has revealed a trade-off between how far athletes push before loading the sled and the success of the loading phase, challenging the notion that athletes should simply maximise pre-load velocity. This appears to align with previous work where increases in skeleton athletes' sprint abilities enhanced pre-load velocity and distance, yet had an unclear influence on overall start performance, seemingly due to a reduction in the effectiveness of the loading phase (Colyer, Stokes, Bilzon, & Salo, 2016).

The mechanism for this trade-off between pre-load conditions (distance and velocity) and the success of the loading phase is yet to be fully elucidated and more research is required to understand the neuromuscular or biomechanical reasons behind these relationships. However, as pre-load velocity increases, one can assume that ground contact times become shorter, especially on negative gradients (Weyand, Sternlight, Bellizzi, & Wright, 2000) such as the push-start sections of skeleton tracks. During sprint running-based tasks, there will inevitably be a velocity at which an athlete can no longer generate positive net impulse (and thus, can no longer accelerate) across the progressively shorter ground contact periods. This velocity will likely be dictated by the athlete's ability to rapidly generate high forces at high velocity, as previously discussed in relation to track and field sprinting (Morin et al., 2012; Weyand et al., 2000). In fact, the ability to generate force at high velocities has previously been identified as a key determinant of skeleton start performance (Colyer, Stokes, Bilzon, Cardinale, et al., 2017) with the more physically-developed athletes also loading the sled later and with higher velocity (Colyer, Stokes, Bilzon, & Salo, 2017). During a skeleton athlete's final steps before loading, the sled is generally in front of (and slightly lateral to) the athlete and is being accelerated by gravity. Conceivably, a sufficient amount of force must be rapidly generated by the athlete on to the track (and perhaps the proportion of force transferred to the sled must also be reduced to an extent) in order to increase the velocity of the athlete's centre of mass relative to the sled and to allow the positions of the athlete and sled to converge. If this is not achieved or possible, it is plausible that athletes have to pull back and decelerate the sled to a greater extent in order to load, which is likely to increase the velocity drop during the loading phase and decrease the overall load effectiveness.

The trade-off between pre-load velocity and load effectiveness is evident in this study, and a balance must therefore be achieved between attaining high velocity before loading and loading the sled successfully in order to produce favourable performance outcomes. Thus, an important step was to assess whether individual athletes' start performances can be enhanced through the modification of pre-load conditions. To investigate this, the athletes were asked not to run to specific distances, but to perform their normal start and then attempt to shorten or lengthen their push distances in comparison to their norm. The loading distance which resulted in the highest sled acceleration index for individual athletes was found to differ amongst the group involved in this study. For all three elite-squad and two talent-squad (T2 and T3) athletes (to whom we were able to carry out the individualised analysis), it was clear that the short loading distance intervention did not have favourable performance outcomes and start performances were superior when athletes ran to their preferred distance before loading compared with the short distance (Figure 3).

The athletes' perceptions of their most favourable loading distance, therefore, appear to be accurate in these more experienced athletes and this may reflect skill refinement across the large number of push-start runs performed by these elite-squad athletes. Alternatively, it is possible that due to this accumulation of push-track runs over their career, the elite-squad athletes are more accustomed (compared with the talent-squad athletes) to the motor pattern associated with loading at a certain distance. Consequently, any alteration from this is likely to feel unfamiliar and potentially uncomfortable, as recently discussed in relation to modifications of sprint start technique (Salo, Gayen, Patterson, & Wilson, 2016). While these types of intervention

studies involving elite athletes are very rare, they are complicated by this difficulty to account for the effect of repeatedly performing the same movements, in the same way, across many prior training sessions. On the other hand, superior performances were sometimes exhibited in one of the intervention conditions for the talent-squad athletes. This can perhaps be attributed to the relatively fewer number of cumulative push-starts performed by talent-squad athletes due to their shorter training history and thus they may have refined their push-starts to a lesser extent than the elite squad.

As different athletes' performances benefitted from adopting different loading strategies, it seems that some individuals are better able to preserve loading phase performance when transitioning to the longer loading distances than others. This is supported by the observed variation in the gradients of the within-athlete correlations between both pre-load conditions (velocity and distance) and load effectiveness (Figure 2). However, the factors which allow some athletes to better maintain load effectiveness when pushing to longer distances and higher velocities are currently unknown and were beyond the scope of this study. Kinematic analyses of the athlete in conjunction with the sled velocity data could provide some insight into the interaction between the athlete and the sled, and the potential disparities between athletes' loading abilities at higher velocities.

This study is the first to specifically assess the effect of altering loading distance on the sled velocity profile and overall start performance of individual skeleton athletes. A strength of this approach was that athletes were allowed to find their own solution to the intervention rather than placing constraints on their performance. The unique method of using a magnet encoder on the sled wheel (to analyse the velocity profile

data) was verified against the independent distance measurement (photocell system). Over a known 50-m distance (from 5-55 m) the encoder consistently yielded a 1-2% difference, which could be largely attributed to the sled wheel slipping at set points on the track. As this typically occurred in the post-load phase, it made very small differences to the pre-load distances and velocities recorded, and it was concluded that the method adopted here was sufficiently robust. However, as is the case for much of the research within the domain of sport and exercise science (especially that involving elite athletes), the absolute sample size is small and thus the applicability to other athletes may also be limited. This is a continuing challenge for sports science researchers as (by definition) elite athletes are a small group of extraordinary individuals. In fact, the number of athletes involved in the current study actually represents two thirds of the available competitive athlete population in this country. It is very rare for research to be granted such access to high-calibre athletes during training, perhaps due in part to the apprehension of athletes and coaches to adhere to the level of control required in these experimental studies (Kearney, 1999). As such, applied research that investigates the influence of coaching or training interventions in a real-world setting is scarce in the scientific literature, which adds to the novelty of the current study.

Conclusions

Loading the sled later during the skeleton start was associated with higher pre-load velocities but less effective loading phases. This trade-off warrants consideration when attempting to enhance start performance by altering loading distance. Importantly, maximising pre-load velocity does not always appear to be the most favourable starting strategy in skeleton, which is likely to be dependent on the physical capacities of each

individual athlete (Colyer, Stokes, Bilzon, & Salo, 2017). Perceptions of the loading distance that resulted in the fastest start performances were generally found to be accurate in the more experienced elite-squad athletes, who appear to have fine-tuned their performances on the push-track. However, simply modifying the distance of the loading phase could lead to performance enhancement in less experienced athletes. Using such an approach to systematically manipulate the loading distance of emerging and talented athletes may allow them to arrive at their most favourable loading distance more readily. This should be regularly revisited to ensure that the adopted loading strategy is altered as training and performance progress. Finally, as a previous study using computer simulation has shown loading strategy to influence sled velocity development in bobsleigh (Leonardi, Komor, & Dal Monte, 1987), this process has potential utility within other winter sliding sports.

Disclosure of interest

No potential conflict of interest was reported by the authors.

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Figure Captions

Figure 1. A typical sled velocity profile of a skeleton push-start illustrating the identification of pre-load and post-load time-points, and the definitions of load effectiveness and velocity drop. Reproduced from Colyer et al.(Colyer, Stokes, Bilzon, & Salo, 2017) with permission from Taylor & Francis Ltd. (Abingdon, Oxon, UK; www.tandfonline.com).

Figure 2. Within-athlete relationships between pre-load velocity, pre-load distance, load effectiveness and velocity drop ($n = 10$) and combined correlation coefficients (all 10 individual athletes' correlation coefficients combined). Each symbol represents an individual athlete and linear trendlines represent within-athlete correlations.

Figure 3. Differences (effect size \pm 90% CI) in start performance (sled acceleration index) between three loading conditions for individual athletes ($n = 7$). E data labels denote elite-squad athletes. T data labels denote talent-squad athletes. Bars represent 90% confidence intervals and the central area (0.0 ± 0.2) indicates a trivial effect. Percentages in brackets (presented only when a clear effect is detected) represent the likelihoods that the effect (right vs. left condition) is negative | trivial | positive.

Figure 1

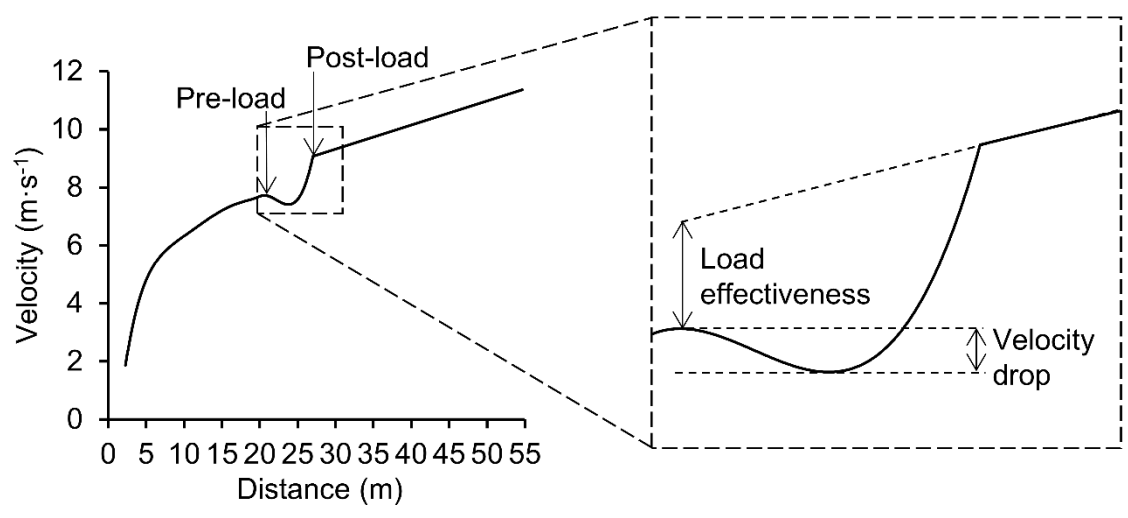


Figure 2

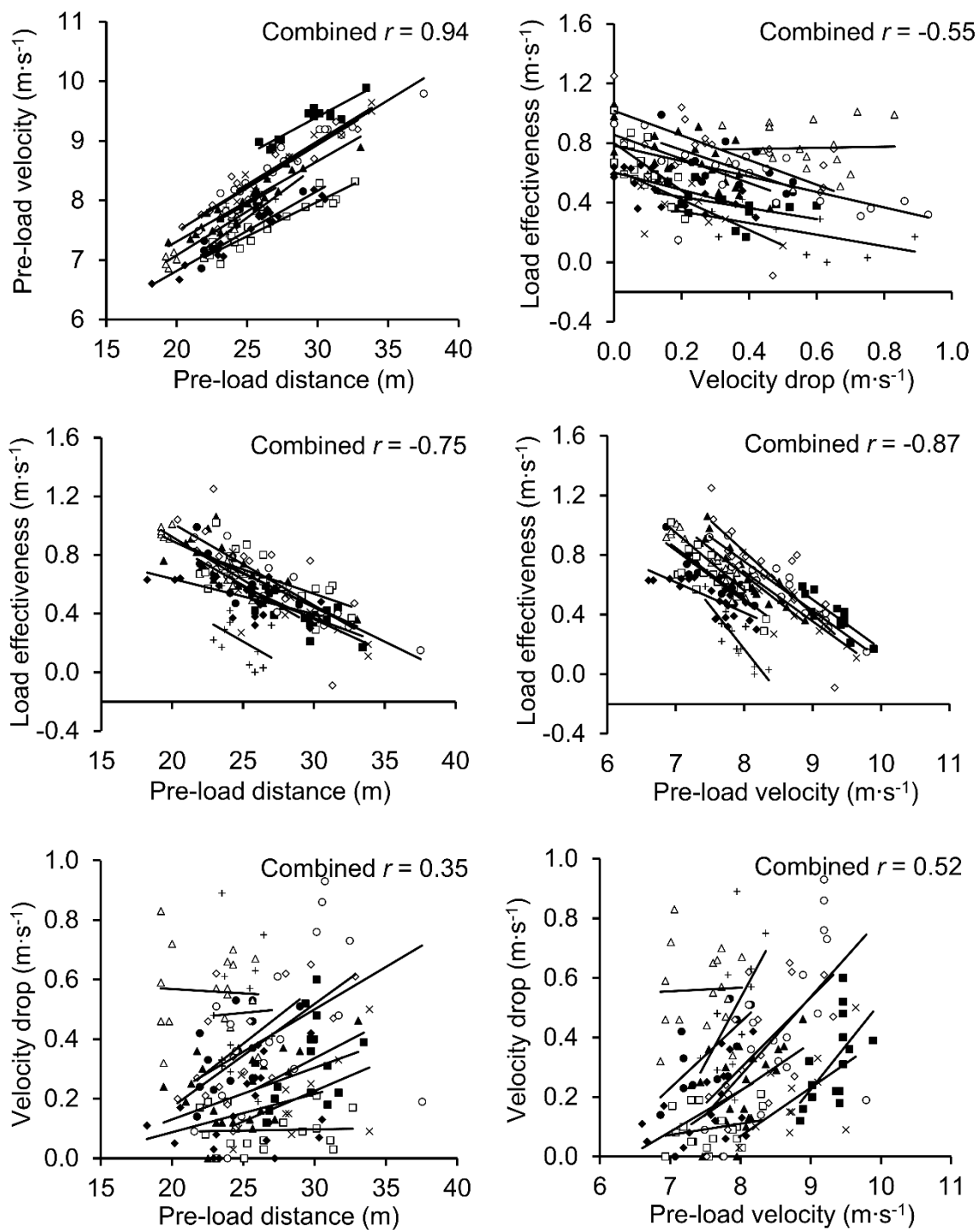


Figure 3

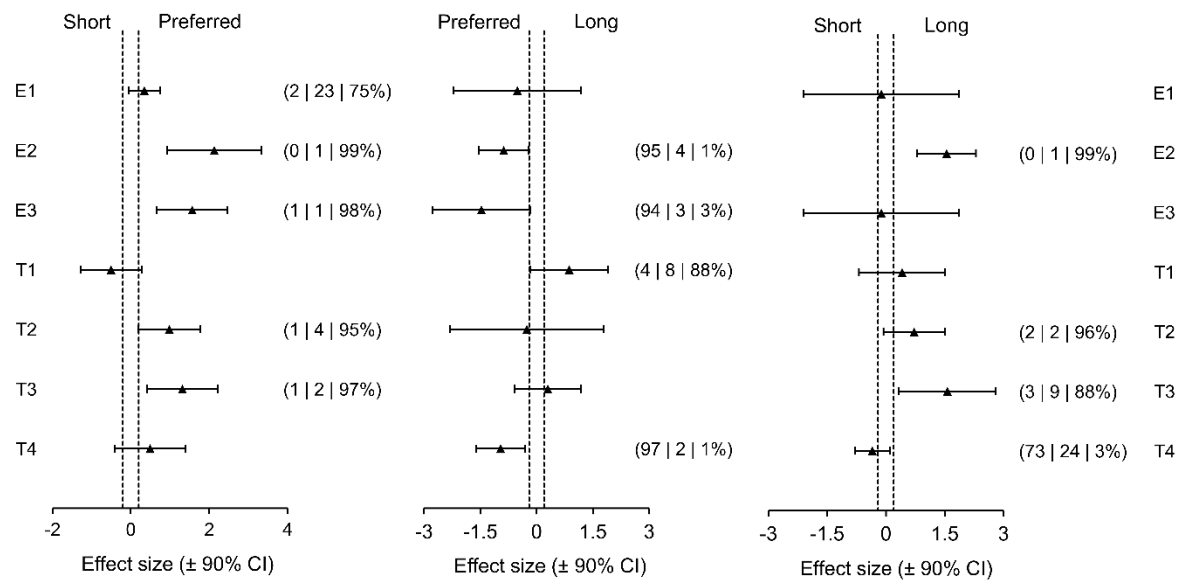


Table 1. Start performance descriptors (mean \pm SD) in three loading conditions.

	Loading condition			Magnitude based inference
	Short	Preferred	Long	
Number of steps	14.4 \pm 1.2	15.9 \pm 1.2	17.4 \pm 1.3	P > S L > P L > S
Pre-load velocity (m·s ⁻¹)	7.74 \pm 0.68	8.15 \pm 0.62	8.53 \pm 0.65	P > S L > P L > S
Pre-load distance (m)	23.18 \pm 2.19	25.63 \pm 1.76	28.60 \pm 2.68	P > S L > P L > S
Velocity drop (m·s ⁻¹)	0.24 \pm 0.15	0.36 \pm 0.19	0.41 \pm 0.19	P > S L > S
Load effectiveness (m·s ⁻¹)	0.66 \pm 0.22	0.55 \pm 0.18	0.39 \pm 0.17	S > P P > L S > L
Sled acceleration index	2.56 \pm 0.21	2.59 \pm 0.22	2.58 \pm 0.21	

> denotes value is substantial greater than the other. S, P, L denote short, preferred and long, respectively