Upper-Body Anthropometric and Strength Measures and Their Relationship to Start Time in Elite Luge Athletes

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Abstract

Crossland, BW, Hartman, JE, Lon Kilgore, J, Hartman, MJ, and Kaus, JM. Upper-body anthropometric and strength measures and their relationship to start time in elite luge athletes. *J Strength Cond Res* 25(10): 2639–2644, 2011—Start time has been shown to be a significant predictor of overall performance in the sport of luge. The starting motion in luge has been described as an explosive upper-body movement that requires significant technique and skill to perfect. This study aims to investigate upper-body factors that may relate to start time in luge. Twenty-two subjects participated in the study as part of their normal off-season training. Each subject had a minimum of 3 years' experience in the sport of luge, and at the time was a member of a U.S. Luge National Team. Subjects completed a 1 repetition maximum (1RM) in the bench press (BP), prone row (PR), and weighted pull-up (WP). Anthropometric distances were taken measuring finger-tip span (FS), biacromial breadth (BB), acromio-radial length, acromio-olecranon length (AO), hand length, and sitting cervical height. Subjects were divided into 2 groups based on which U.S. Luge National team they were currently a member of, Senior National (SN, $n = 13$) and Junior National (JN, $n = 9$). A Pearson product–moment correlation coefficient showed several significant ($p \leq 0.05$) relationships between upper-body variables and start time among the groups. The BP and PR 1RM were shown to have a significant relationship in both groups. Among the anthropometric variables, AO was also significant in both groups. The WP, FS, BB, and height were all shown to have a significant relationship with start time in the SN group, but not in the JN group. These results suggest that as luge athletes become more efficient in the starting technique, outside factors such as upper-body strength and anthropometric measures play a larger role in performance.

Key Words arm length, bench press, prone row, sliding sports

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Introduction

During the 2010 Winter Olympic Games in Vancouver, after navigating 4 runs and almost 4,000 m of track, the time between first and sixth places in the women's luge competition was <1 second (3). In a sport that is often decided by thousandths of second, it is important for athletes and coaches to fully understand the determining factors that affect one's performance. Performance in the sport of luge is measured by the time it takes an athlete to navigate an icy track, with the winner having the lowest combined time. Research has shown that several factors such as environment (1,5), track conditions (5), start order (5), temperature (1,5), start time (1,4,5,10), and equipment (8) can affect performance in sliding sports (bobsled, skeleton, luge). Among these factors, start time has been shown to be the most significant predictor of performance in sliding sports (1,4,5,10), but little research has investigated factors that may affect luge start time.

The starting motion in luge can be described as an explosive upper-body movement that requires the athlete to accelerate the sled by pulling on 2 stationary handles and then paddling quickly with their hands before settling in the sled (8,9). According to U.S. Luge (9), the start is broken down into 6 phases: the block, compression, the pull, extension, push, and paddles. The starting motion begins with the block. The athlete rocks the sled forward in advance of the start handles and leans back with the upper torso. The block is mainly a preparatory motion for the remainder of the start, similar to prestretching before a vertical jump. The block is followed by the compression phase, which begins as soon as the sled starts its backwards motion. In this phase, the athlete accelerates the sled backward using the hips until the trunk is in full flexion to use the stretch shortening cycle for the start of the forward motion. Next comes the pull, which is the first phase where the athlete is actually pulling against the start handles. The pull is very short and is characterized by the athlete accelerating the sled by extending the torso. After the pull is the extension phase, which is the longest phase of the luge start, and often thought of as the most important. During this phase, the athlete is still extending the torso while at the same time, keeping the back tight and pulling with maximal force against the start handles. The extension phase ends when the hips reach the start handles and the push phase begins. At this point, the torso should be flexed to 90° while the athlete actively pushes against the start handles as the arms extend behind the athlete. The last phase of the starting motion is the paddles. Depending on the track, the athlete will take between 3 and 6 paddles against the ice before settling into the sled. The athlete uses either the bottoms of the fingers or the top of the knuckles to paddle depending on personal preference. Athletes are also allowed to wear spikes with a maximum length of 4 mm on their gloves to help gain traction during the paddles. The goal of a properly performed start is for the sled to be going at its maximum velocity after the last paddle is taken and the athlete has settled into the sled (9).

The start is the only time during a run that a luge athlete can physically accelerate the sled (9). Throughout the remainder of the run, the athletes are at the mercy of gravity and must try to maximize their speed by finding the best lines down the track. Upper-body strength and power are the focus of off ice training for luge athletes (9), but little research has been done investigating their relationship to start time. Researchers, coaches, and athletes can all agree that the start time is one of the most important factors that affect performance in luge. Therefore, the purpose of this study was to determine the relationships between upper-body physiological factors and luge start time. By understanding some of the determining factors that affect the luge start, coaches and athletes will be better educated in designing an off ice training program.

Methods

Experimental Approach to the Problem

This study used a cross-sectional research design to determine what relationships exist between a luge athlete's start time and various upper-body measures. Several upper-body anthropometric and strength measurements were gathered from archival data in an attempt to find important factors that affect an athlete's start time. Six upper-body anthropometric measures were taken which include hand length, biacromial breadth (BB), sitting cervical height, finger-tip span (FS), acromio-radial length (AR), and acromio-olecranon length (AO). Upper-body strength was tested by determining a 1 repetition maximum (1RM) for the following lifts: bench press (BP), prone row (PR), and weighted pull-up (WP). Athletes also completed a 15-second pull-up test in which they recorded the maximum number of pull-ups they could perform in 15 seconds. Selection for upper-body strength tests was based on the physical testing requirements of U.S. Luge. These tests are used to gauge off ice progress and to aid in the selection of all U.S. Luge Association teams. Testing was performed over 2 days with each subject following the exact testing protocol. All data were collected by a U.S. Luge Association strength and conditioning coach.

Subjects

Twenty-two male and female subjects between the ages of 16 and 36 participated in the study. All subjects at the time of data collection were on either the U.S. Luge Senior National Team or the U.S. Luge Junior National Team. All subjects had a minimum of 3 years of experience in the sport of luge and a minimum of 1 year of formal weight training experience under the guideline of a U.S. Luge Strength and Conditioning coach. At the time of data collection, all subjects had followed the same training protocol in the 8 weeks before both the strength and start tests. Among the subjects were Olympians from the 1998, 2002, 2006, and 2010 Olympic Winter Games. All subjects provided consent for their measurements to be used in the analysis of their training. All measurements analyzed in this study were taken by a U.S. Luge strength and conditioning coach during normal preparations for the upcoming luge season, and analyzed retrospectively. Because of the data being analyzed retrospectively, controls for hydration, nutrition, and time of day were unavailable. Descriptive statistics, strength and power measures, and anthropometric distances, mean ± *SD*, for the 2 groups are shown in Tables 1 and 2.

Table 1. Descriptive statistics for the Senior National Group (mean ± *SD*).*

Physical characteristics	
Age (y)	26.46 ± 5.72
Height (cm)	176.32 ± 8.27
Weight (kg)	76.32 ± 10.33
Experience (y)	13.92 ± 5.15
Upper-body strength tests	
Bench press 1RM (kg)	95.08 ± 20.3
Prone row 1RM (kg)	84.69 ± 17.59
Weighted pull-up 1RM (kg)	54.27 ± 9.86
15-s Pull-up test (reps)	15.31 ± 2.49
Anthropometric measures (cm)	
Finger-tip span	179.52 ± 6.6
Biacromial breadth	43.80 ± 4.18
Hand length	18.68 ± 0.95
Acromio-radial distance	59.93 ± 3.52
Acromio-olecranon distance	40.28 ± 2.5
Sitting cervical height	61.00 ± 12.7
Start time (s)	1.342 ± 0.05

*1RM = 1 repetition maximum.

TABLE 2. Descriptive statistics for the Junior National Group (mean ± *SD*).*

Physical characteristics	
Age (y)	17.67 ± 1.00
Height (cm)	174.70 ± 8.29
Weight (kg)	75.64 ± 10.78
Experience (y)	6.67 ± 2.92
Upper-body strength tests	
Bench press 1RM (kg)	98.95 ± 20.71
Prone row 1RM (kg)	81.17 ± 14.29
Weighted pull-up 1RM (kg)	50.00 ± 9.51
Anthropometric measures (cm)	
Finger-tip span	177.34 ± 11.0
Biacromial breadth	40.83 ± 3.05
Hand length	18.36 ± 1.09
Acromio-radial distance	60.66 ± 3.41
Acromio-olecranon distance	39.68 ± 2.44
Sitting cervical height	65.93 ± 3.39
Start time (s)	1.368 ± 0.04

*1RM = 1 repetition maximum.

Procedures–Strength

Upper-body strength testing was broken up into 2 days of testing with 2 days of complete rest between sessions. On day 1, each subject completed a 1RM in the BP followed by 10 minutes of rest and then performed the 15-second pull-up test. On day 2 of testing, each subject completed a 1RM for the PR followed by 10 minutes of rest and then completed a 1RM for the WP. Each subject adhered to the following protocol for each test:

Fifteen-Second Pull-Up Test. Equipment used for this test was a pull-up bar 1.25 in. in diameter. Subjects were instructed to grasp the bar with a pronated grip keeping the hands a minimum of 27.5 in. apart. Subjects started the test motionless from the hanging position with the clock starting as soon as the subject initiated the upward movement. To keep athletes from swinging horizontally, a coach placed his hands on both sides of the athlete's abdomen. The subjects were instructed to pull-up until their chin was level with the bar while keeping their head in a neutral position. Subjects' knees were allowed to bend as long as it caused no horizontal movement. Subjects were required to lower themselves until their arms were fully extended. Successful pull-ups were counted when the subjects' chin was parallel to the bar. Each subject's score reflected the amount of successful pull-ups that were completed in 15 seconds.

Bench Press. Subjects were instructed to lie flat on the bench with their feet, head, shoulders, and buttocks in contact with the bench. Subjects were then instructed to grasp the bar with a pronated grip with their hands no wider than 32 in. apart. After this, a spotter helped the subject remove the bar from the rack. The subject then lowered the bar until it came in contact with the chest and then returned the bar to the starting position. A subject's lift was disqualified if there was any movement of the feet, head, shoulders, or buttocks from their original position. After warming up to 80% of their previous 1RM, each subject was allowed to take a maximum of 5 attempts to find a 1RM with a minimum of 2 minutes of rest between each attempt. The subject's heaviest successful attempt was recorded as their 1RM.

Prone Row. To find each subject's 1RM for the PR, the researcher used a high PR bench (Samson Equipment; Las Cruces, NM, USA). Each subject was instructed to lie on the bench face down, keeping his or her head, chest, and legs flat for the entire lift. The subjects then gripped the bar with a pronated grip having their hands no >32 in. apart. The subject then removed the bar from the bench supports and let it hang freely. When the bar was motionless, the subject raised the bar toward his or her chest until it came in contact with the high PR bench. Subjects' lifts were disqualified if any part of their body came out of contact with the bench or if the bar did not touch the bench. The heaviest successful attempt for each subject was counted as 1RM.

Weighted Pull-Up. Equipment used for this test was a pull-up bar 1.25 in. in diameter and a nylon strap approximately 2 in. wide and 4 ft. long. The strap was wrapped around the athletes' waist and then wrapped around a dumbbell, allowing the dumbbell to hang in between the subjects' legs during the pull-up. The subjects grasped the bar with a pronated grip keeping the hands a minimum of 27.5 in. apart. The test began with the athletes being motionless and then pulling themselves upward keeping their lower body straight and their head in a neutral position. Once the subject's chin was parallel to the pull-up bar, the test was completed. The subjects were allowed to take as many warm-up attempts as needed. The highest weight lifted on the test was recorded as the subject's 1RM WP.

Procedures–Anthropometry

Anthropometric measures were taken on one of the 2 rest days between upper-body strength tests. All anthropometric measures were taken using a Bodycare anthropometric measuring tape (Bodycare Inc.; Southam, Warwickshire, United Kingdom). The following anthropometric measures were taken for each subject: BB, AO, AR, hand length, sitting cervical height, and FS. Each anthropometric distance was taken on the dominant side of the body where applicable and measured to the nearest millimeter. The following protocol was used for each measure.

Biacromial Breadth. The subjects were instructed to stand erect with their back facing the researcher. The subject was then instructed to stand with a neutral posture with a noticeable kyphotic curve in the spine. The researcher then measured the distance between the lateral border of left and right acromial processes.

Hand Length. Subjects were instructed to stand erect in the anatomical position, palms facing outward and fingers fully extended. The researcher then located the point midway between the subjects' ulnar and radial styloid process. From this point, the researcher measured the distance between the midpoint of the interstylon line and the tip of the subjects' middle finger.

Acromio-Olecranon Length. The subjects were instructed to stand erect with their right arm flexed 90° at the elbow with the palm pronated. The researcher then stood behind the subject and located the acromion process. The researcher then measured the distance between the most upper edge of the posterior border of the acromion process and the olecranon process.

Acromio-Radial Length. The subject was instructed to stand erect with palms pronated. The researcher then located the subject's acromion process. The researcher then measured the distance between the most upper edge of the posterior border of the acromion process and the subject's radial styloid process.

Sitting Cervical Height. The subjects were instructed to sit on the floor with their feet extended in front of them. The subjects were then instructed to sit with neutral posture while having a noticeable curve in their spine. The researcher then measured the distance from the spinous process of the subject's seventh cervical vertebra and the floor.

Finger-tip Span. The subjects were asked to stand with their back facing the researcher. The subjects were then instructed to abduct the shoulder joint until the humerus was parallel to the floor and then extend their arms as far as possible. The researcher then measured the distance between the tips of the subject's middle fingers.

Procedures–Start Time

Measures for start time were taken from archived results of the 2007 JetBlue Airways U.S. National Start Championships, which took place indoors on the fully refrigerated start ramps at the headquarters of U.S. Luge in Lake Placid, NY. All subjects were required to use sleds, race clothing, and protection according the International Luge Federation (FIL) rulebook. In addition, timing eyes and start handles conformed to all FIL rules and regulations. The subject's start time was measured as the time it took the front of the sled to pass through timing eyes placed 1 and 11 meters away from the start handles. Each subject completed 2 starts with the faster of the 2 starts being the subject's score for the start test.

Statistical Analyses

For statistical analysis, subjects were split into 2 groups, Senior National (SN) and Junior National (JN) Team Groups (based on the U.S. National Luge team of which he or she was currently a member of). All statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS for Windows, SPSS, Inc., Chicago, IL, USA). Scores for the 15-second pull-up test were unavailable for the JN group. Descriptive means (*SD*) were determined for the following measures in both groups: height (m), weight (kg), years of experience (years), age (years), 1RM PR (kg), 1RM BP (kg), WP (kg), start test (seconds), and all anthropometric measures (cm). For the SN group, descriptive means (SD) were also found for 15-second pull-up test. A Pearson product–moment correlation coefficient procedure was performed to investigate any relationships that may exist among the tested variables and start time. In addition, a post hoc forward stepwise regression analysis was performed to estimate additive effects of measured variables on start time. For all statistical analyses, statistical significance was set a priori at $p \leq 0.05$.

Results

The results of a Pearson product–moment correlation showed several significant relationships with start time among the groups. These results can be observed in Tables 3 and 4 for the SN group and JN group, respectively. Among all the variables tested, 3 (acriomio-olecranon distance, BP 1RM, and PR 1RM) were significant in both the SN and JN groups. In the SN group, height had the strongest relationship ($r = -0.62$) to start time among the anthropometric measures, and PR 1RM had the most significant ($r = -0.82$) relationship to start time among the strength measures. For the JN group, only acomio-olecranon distance showed a significant ($r = -0.74$) relationship to start time for the anthropometric measures, whereas both PR and BP both were shown to have the same statistical significance ($r = -0.76$) with regard to start time.

Table 3. Pearson product–moment correlation coefficients between start time and upper-body variables in the Senior National Group ($n = 13$).*

Upper-body strength testing	
15-s Pull-up test (reps)†	$r = -0.69$
Bench press 1RM (kg)†	$r = -0.76$
Prone row 1RM (kg)†	$r = -0.82$
Weighted pull-up 1RM (kg)†	$r = -0.81$
Anthropometric measures (cm)	
Finger-tip span†	$r = -0.58$
Biacromial breadth†	$r = -0.71$
Hand length	$r = -0.51$
Acromio-radial distance	$r = -0.53$
Acromio-olecranon distance†	$r = -0.58$
Sitting cervical height	$r = -0.12$
Height†	$r = -0.62$

*1RM = 1 repetition maximum.
†Statistical significance at $p \leq 0.05$.

Table 4. Pearson product–moment correlation coefficients between start time and upper-body variables in the Junior National Group ($n = 9$).*

Upper-body strength testing	
Bench press 1RM (kg)†	$r = -0.76$
Prone row 1RM (kg)†	$r = -0.76$
Weighted pull-up 1RM (kg)	$r = -0.64$
Anthropometric measures (cm)	
Finger-tip span	$r = -0.64$
Biacromial breadth	$r = -0.62$
Hand length	$r = -0.64$
Acromio-radial distance	$r = -0.56$
Acromio-olecranon distance	$r = -0.74$†
Sitting cervical height	$r = -0.31$
Height	$r = -0.61$

*1RM = 1 repetition maximum.
†Statistical significance at $p \leq 0.05$.

After performing a post hoc forward stepwise regression analysis among all subjects, it was found that PR was the only significant predictor of start time with a multiple *R*-value of 0.82. Although PR was the only significant predictor of start time, when paired with the following variables in a forward stepwise regression, the multiple *R*-value was raised to 0.88: acromio-olecranon distance ($r = 0.84$), FS ($r = 0.86$), BP ($r = 0.87$), WP ($r = 0.87$), height ($r = 0.88$), and years of experience ($r = 0.88$).

Discussion

It is commonly accepted in sliding sports that time lost during the start can be tripled by the end of the run (9). Previous research on the sliding sports has focused on factors that affect the overall performance. Bruggemann et al. (1) investigated the 2-man bobsled, 4-man bobsled, and luge events for several factors such as air temperature, track temperature, starting order, and split times. The results of their study found that in all 3 events, a fast start time was a prerequisite for a good final ranking. These results were confirmed by Morlock and Zatsiorsky (5) who looked at different split times, ice temperature, and start order for the 4-man bobsled event and determined that start time was shown to have the strongest relationship to finish time. Additionally, Zanoletti et al. (10) found that the start time accounted for 23 and 40% of overall performance in skeleton for men and women, respectively. Although luge, bobsled, and skeleton are different in some aspects, they are collectively considered gravity sports, and the start seems to be the most important nonenvironmental factor with regard to finish time among all 3 sports.

As mentioned previously, the luge start is a highly technical movement which can take years to perfect. Athletes focus a bulk of their off-season training the start on indoor refrigerated start ramps to improve their technique. As an athlete gets more efficient in the starting movement, it seems that outside factors such as anthropometric measures and upper-body strength play a larger role in the starting motion. The results of the study found 8 (BB, FS, acromio-olecranon distance, height, BP 1RM, PR 1RM, WP 1RM, 15-second pull-up test) significant factors for the SN group with regard to start time, but only 3 (acromio-olecranon distance, BP 1RM, PR 1RM) significant factors in the JN group. It is the opinion of the researchers that these differences among the groups can be explained by the years of experience, and efficiency of the start technique. The SN group averaged over twice as much experience as the JN group, 13.9 years as compared to 6.6 years.

The results of this study indicate that upper-body strength plays a significant role in the starting motion. In both groups, PR was the only variable that was shown to be a good predictor of start time. These findings echo that of Platzer et al. (6), who found isometric pulling strength had a significant relationship to start speed. It was determined that isometric bench pull strength played a more significant role in starting speed in luge athletes than measures of countermovement vertical jump, isometric leg strength, and flexibility and start time. Based on these findings, it appears that upper-body strength is the most important factor in achieving a fast start for luge athletes (6). In this study, BP 1RM was also found to be a significant factor in both groups, which suggests that pushing strength may be just as important for luge athletes as pulling strength. It is recommended that luge athletes should incorporate both the agonist and antagonist muscled groups involved in the starting motion. Because the starting motion is very ballistic in nature, it may be beneficial to look at more explosive type exercises and how they relate to the luge start.

Research has shown that some anthropometric distances can be good predictors of an athlete's performance in certain sports (2,7). The results of this study found that some increased upper-body measures may lead to a faster start in luge. For both the JN and SN groups, acromio-olecranon (shoulder to elbow) length was found to have a significant ($r = -0.74, -0.58$) relationship to start time. Total arm length was also measured but found to have no significant relationship to start time, which suggests that upper-arm length may play a more important role than total arm length with regard to the starting motion. This may be because the muscles of the upper arm have a much larger cross-sectional area, as compared to the muscles of the lower arm, and therefore are capable of producing greater force throughout a longer range of motion during the start movement.

During the final phase of the start, known as the paddling phase, athletes use their hands to paddle against the ice to increase the speed of the sled. The results of the correlation matrices indicated that hand length was not a significant factor with regard to the entire starting motion in either of the groups. Future research may investigate hand length and its relationship to only the paddling phase of the start, because during this phase, the hands are the prime movers. Research may also investigate how much, if any, contribution the paddling phase gives to the overall start motion. The first 5 phases of the start are all explosive movements and can generate much more force than the paddling phase; therefore, the significance of this phase should be examined further to understand its importance.

The findings of this study and those previously published should be useful for athletes, coaches, and strength and conditioning personnel wishing to develop effective training and conditioning programs for luge competitors. Luge athletes may benefit from improved start performance and should regularly engage in strength and conditioning activities designed to improve upper-body strength.

Practical Applications

Upper-body strength becomes increasingly more important to luge athletes as they become more efficient with the starting technique. At the time of the data collection, BP 1RM, PR 1RM, weighted pull-up, and 15-second pull-up test were all tests used by U.S. Luge to gauge performance for upper-body strength. It is the opinion of the researchers that these tests are good indicators of an athlete's potential starting abilities and should remain a part of the testing protocol for luge athletes. Less experienced athletes may benefit more from a training program that focuses on improving start mechanics, but as athletes progress, upper-body strength should be emphasized in the training regime. Prone Row, or similar pulling motions, could be a useful tool in measuring an athlete's starting capabilities off the ice. It is recommended that upper-body strength training focus on both pulling and pushing motions to maximize performance in the luge start. Additionally, athletes with an increased upper-arm length may have a potential advantage over athletes with shorter measurements. These results may be beneficial for coaches at the developmental level as they look to improve their talent identification protocols. Future research may look at each individual phase of the start and explosive type strengthening movements as they relate to the starting motion in luge.

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