Barbell Trajectory, Velocity and Power Changes: Six Attempt and Four World Records

John Garhammer, Ph.D., CSCS.
Director, Biomechanics Laboratory
Department of Kinesiology
California State University
Long Beach, CA, USA.

At the 1999 Junior World Weightlifting Championships, held in Savannah, Georgia one male and two female athletes had the unique experience of being successful with all three of their Snatch lift attempts, and setting junior and senior world records on both their second and third attempts. The six successful snatch lifts of two of these athletes from China were analyzed, and serve as the most recent objective data to indicate how barbell trajectory and velocity change with increasing weight, and to support the concept of using sub-maximal training lifts to increase power output. These six lifts were video taped from the right side of the competition platform using a standard 8mm camcorder. The lifts were analyzed using sophisticated computer based motion analysis software, including both an Ariel Performance Analysis System (APAS), and a Peak Performance Technologies' Motus video analysis system. Technical considerations for such analyses have been published previously (Garhammer, 1993).

Figures 1 and 2 are graphs showing how the vertical barbell velocity, for the three successful snatches of Yanqing Chen and Zhiyong Shi, changes with time during each of the lifts. Note that as the weight lifted increased from the first to the second attempt, and from the second to the third attempt, the time interval from the start of the lift (time = 0) to peak velocity (Vmax) increased, but the peak velocity value itself decreased. This is very evident for Chen's three lifts. Figures 1 and 2 also list the maximum bar heights achieved during each lift (Ymax). Maximum bar heights for the six lifts analyzed were reached approximately 1.0 to 1.1 seconds after the start of the lift, and about 0.2 to 0.3 seconds after maximum velocity. As the bar reaches peak height it stops moving up or down for an instant; this is when its vertical velocity decreases to zero in Figures 1 and 2. Note that the maximum bar heights decreased as the weight lifted increased for each athlete. These bar height differences can clearly be seen in Figures 3 and 4, which show the bar trajectories for the first and third snatch lift attempts of Chen and Shi. All of these changes in the barbell movement characteristics, when comparing lighter lifts to heavier lifts (that is, lighter lifts move faster and higher during shorter time intervals), suggest that power output should decrease as the weight lifted increases, since less work is done over a longer time period.

The term "power" has been used in many ways relative to the strength sports. The correct definition from physics, however, is the rate of doing mechanical work or work done per unit time. The short appendix following this article gives an example calculation of power output for a deadlift. The metric unit of measurement for power is Watts (W), which is familiar to most of us from electrical appliances. One horsepower, a power unit familiar in the United States relative to all types of motors, equals about 746 W. For this article, I used some precise biomechanical measures of power output during the execution of the Snatch lifts discussed above to illustrate how power development during lifting changes as percent of 1RM changes. A short discussion of previously published work rate values from both weightlifting and powerlifting is used to emphasize important concepts for maximizing the power training stimulus obtained from any type of weight training workout.

For precise power output measurements during snatch and clean pulls, a complete pull is defined as occurring during the time interval from the start of the lift (just before the barbell plates lose contact with the platform) until maximum vertical velocity is achieved when the athlete is in the fully extended top pull position. The second pull is defined as occurring from after the bar passes above knee height and the hips are shifted forward toward the bar ("power position") until the top pull position is reached. The second pull involves a stronger pulling position and shorter time interval than the complete pull, resulting in higher power generation. The complete pull analyzed for each of Chen and Shi's three lifts ran from time zero until maximum velocity was reached. Their second pulls occurred during approximately 0.2 seconds prior to maximum velocity. The exact duration of the second pull changes from one athlete to another and from one lifting attempt to the next.

Table 1 lists the power outputs generated by Yanqing Chen and Zhiyong Shi during the complete pull, and second pull only, of their three successful snatch lifts. The power values show that as the weight snatched by Chen and Shi increased from less than 100% of their 1RM to the 1RM limit, the power outputs in fact decreased. Previously published data for snatch and clean pulls (Garhammer, 1993, 1985) indicates, for a given athlete in a given competition, that as the weight lifted increases the duration of the pull increases, and the maximum and average pull velocities, maximum bar height, and power outputs decrease.

Table 1: Power Outputs From Vertical Work On The Barbell During Snatch Lifts.

Athlete	Body Mass (Kg)	Lift (Kg)	% 1 RM	Total Pull (W)	Second Pull (W)
Y. Chen	57.24	95.0	92.7	1,123	2,633
		100.0*	97.6	1,120	2,407
		102.5*	100.0	1,053	2,035
Z. Shi	61.64	142.5	95.0	1,571	3,342
		148.0*	98.7	1,551	3,333
		150.0*	100.0	1,493	3,286

* Junior and Senior World Record

Note: The power output values listed in Table 1 above were calculated from only the vertical work done in lifting the barbell, and do not include the additional work resulting from horizontal barbell motion nor the work done in elevating the center of mass of the athlete's body during the pulling motion. These factors can increase the total power output generated during the complete pull by 20% or more (Garhammer, 1985, 1991, 1993).

The data given and referenced above is derived primarily from biomechanical analyses of elite competition performances in the sport of weightlifting. Similar results have also been found from analyses of elite powerlifting performances (Garhammer, 1993). That is, power generation is higher for sub-maximal lifts. However, the extent of the power output change is greater in the power lifts, particularly the squat and deadlift. A small decrease in weight, about 5%, can often increase power output substantially due to a considerably greater movement speed and shorter time interval for completion of the lift (see the appendix for an example).

There are positive and negative considerations associated with using data from major competitions to study the effects of reducing the weight lifted on power output. The main positive factors include the reasonable assumptions that the athlete is in top condition and has lifted a true 1RM weight. The major negative factor is that the lowest weight lifted during the three competition attempts is seldom below 90% of the 1RM. Since it is of interest to know the percent of one's 1RM weight to use in order to generate maximum power output, competition lift analyses alone will not permit an answer to this question to be determined. However, combining information available from competition, training session and laboratory analyses, it is possible to suggest that for the competition snatch and clean 80 to 85% of the current 1RM will permit maximal or near maximal power generation. For power snatches or power cleans 85 to 90% of the corresponding 1RM is suggested.

It is more difficult to offer a percent of 1RM value for maximizing power output during execution of the power lifts. Remember that a maximal effort must be made to generate maximal power output during a lift. If the weight used in a deadlift is too light the deadlift is really a high pull or power pull as used in training by Olympic weightlifters. A squat can quickly turn into a jump squat, and a bench press can be difficult to hold on to if the weight used is too light and a maximal effort is made. Some additional discussion of this point is currently available in an article on the internet (Garhammer, 2001). Keeping these considerations in mind, it is suggested that 75 to 85% of the 1RM weight be used to produce maximal or near maximal power output with the power lifts.

The results of the analyses presented in this article indicate good consistency in the pulling technique of the athletes evaluated. Changes with increasing weight lifted were what was expected based on earlier biomechanical analyses of world champion weightlifters. Power output was again shown to decrease with increasing weight lifted. Athletes with slower than desired movement speed should train to increase power output by focusing on the use of submaximal weights during preparatory phases of the yearly cycle.

REFERENCES

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APPENDIX

The deadlift is an easy lifting movement to analyze for power output. Consider a 400 Kg 1RM deadlift. A powerlifter completes this lift in 2.5 seconds and raises the bar 0.8 meters (a little more than 2 feet). The power output during this lift is the work done divided by the time required to perform the work. (9.8 m/s/s in the equation below is a conversion factor required to obtain the power value in the unit of watts)

Power = (400 Kg x 9.8 m/s/s x 0.8 m) / 2.5 seconds = 1254 W.

If the weight is decreased 5% to 380 Kg, the same athlete may be able to complete the lift in only 2.0 seconds.

Power = (380 Kg x 9.8 m/s/s x 0.8 m) / 2.0 seconds = 1489 W.

This is a 19% increase in power output compared to the 1 RM lift!

Using the calculation method above, and data obtained with a measuring tape and stop watch (or better still counting video frames using the single picture advance button on a quality VCR - each picture equals 1/30 second with NTSC video in the USA, or 1/25 second with PAL video in most of Europe), you can determine with good accuracy the power output for deadlifts you and your training partners perform during workouts.

Although power output increases more rapidly as weight decreases in powerlifting compared to weightlifting, the absolute level of power generation is much greater for the competitive lifts in the sport of weightlifting (for comparable athletes) due to the very fast movement speeds that are required. An additional factor in calculating power output during snatch and clean lifts is that the pull ends when the barbell is moving upward at maximum velocity (compared to zero velocity at the end of deadlifts, squats and bench presses). This requires a "kinetic energy" term to be included in the power calculation for these types of lifts (Garhammer, 1993).

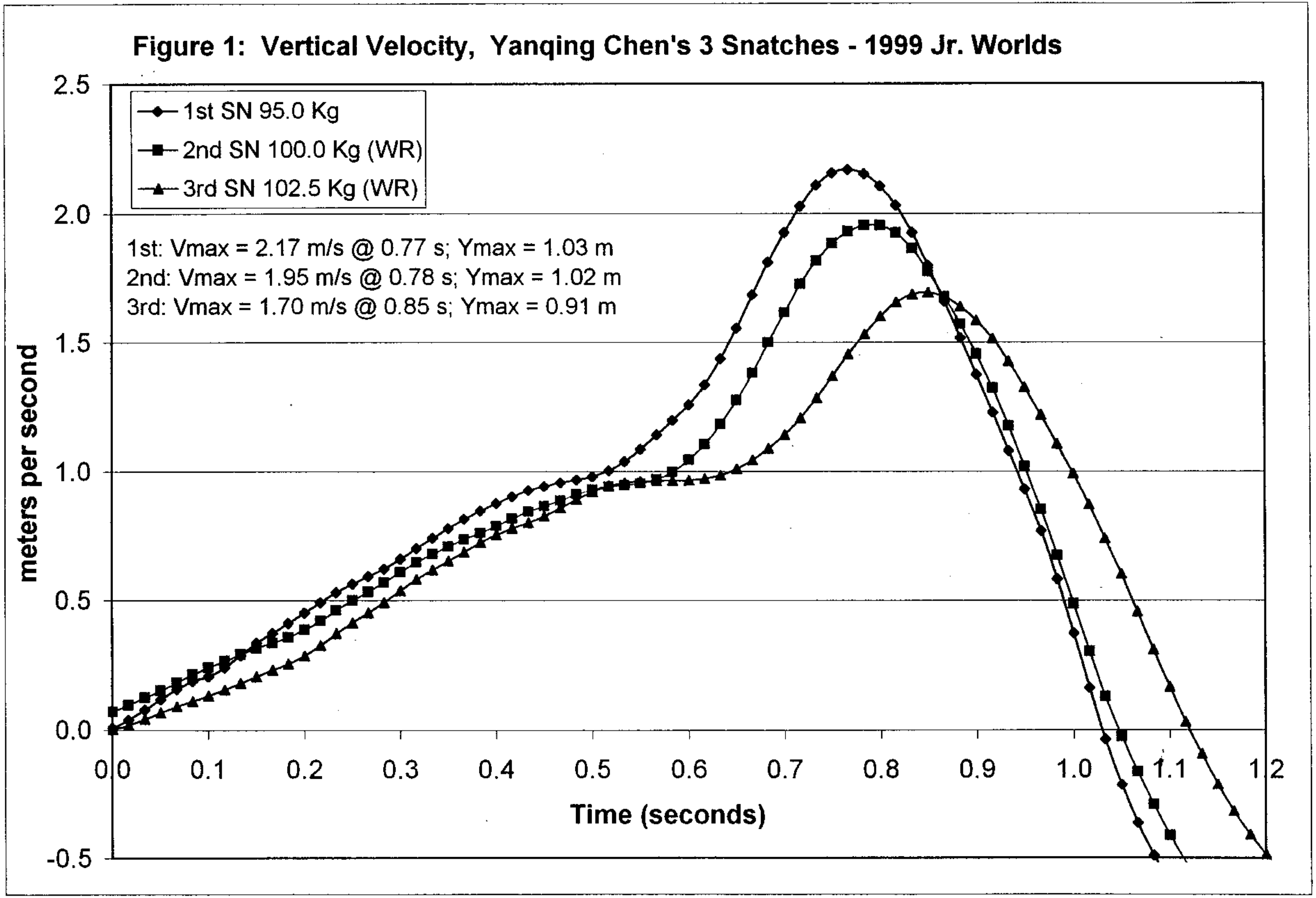
Figure 1: Vertical Velocity, Yanqing Chen's 3 Snatches - 1999 Jr. Worlds
1st SN 95.0 Kg
2nd SN 100.0 Kg (WR)
3rd SN 102.5 Kg (WR)
1st: Vmax = 2.17 m/s @ 0.77 s; Ymax = 1.03 m
2nd: Vmax = 1.95 m/s @ 0.78 s; Ymax = 1.02 m
3rd: Vmax = 1.70 m/s @ 0.85 s; Ymax = 0.91 m
meters per second
Time (seconds)
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2

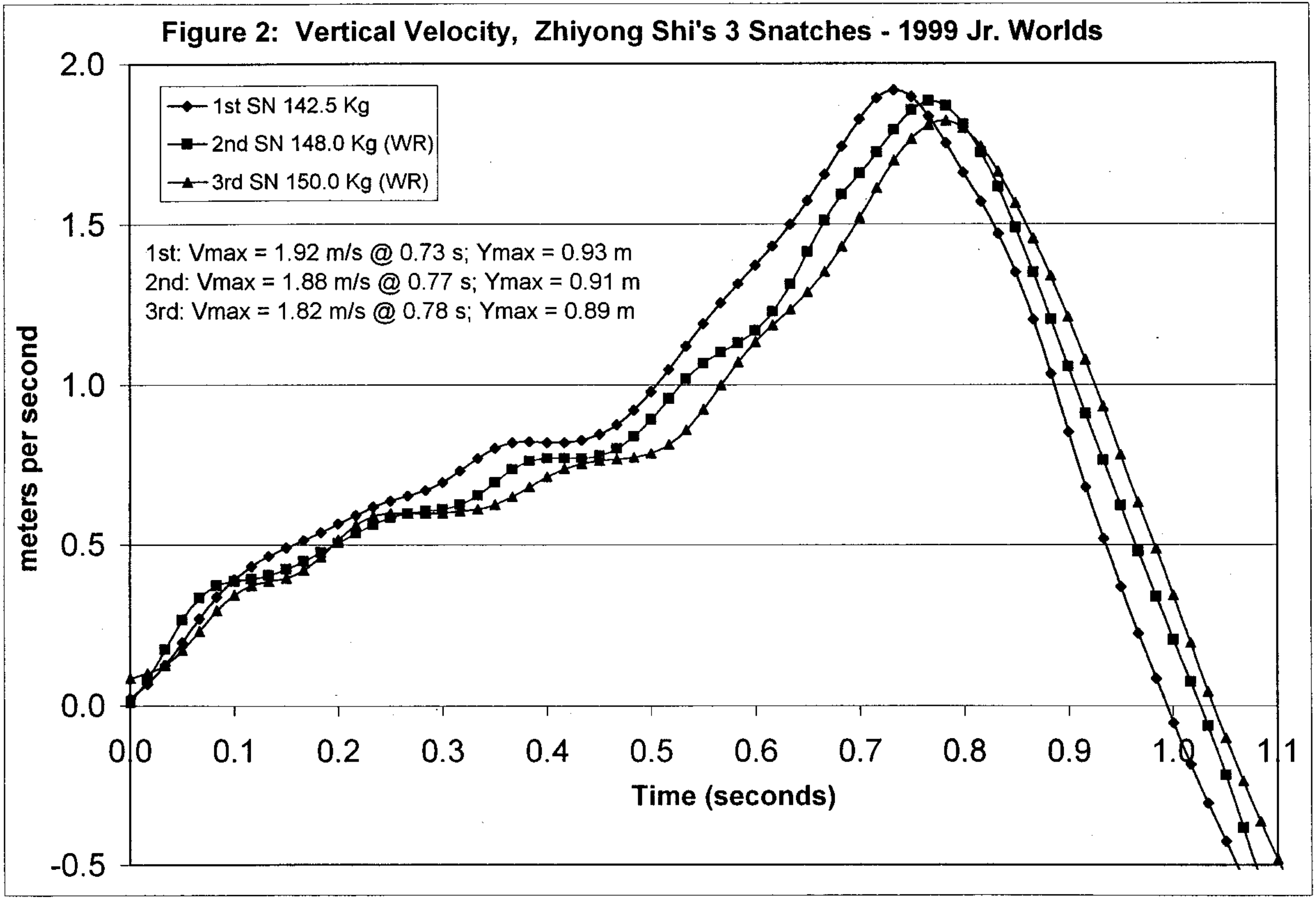
Figure 2: Vertical Velocity, Zhiyong Shi's 3 Snatches - 1999 Jr. Worlds
1st SN 142.5 Kg
2nd SN 148.0 Kg (WR)
3rd SN 150.0 Kg (WR)
1st: Vmax = 1.92 m/s @ 0.73 s; Ymax = 0.93 m
2nd: Vmax = 1.88 m/s @ 0.77 s; Ymax = 0.91 m
3rd: Vmax = 1.82 m/s @ 0.78 s; Ymax = 0.89 m
meters per second
2.0
1.5
1.0
0.5
0.0
-0.5
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Time (seconds)

Figure 3: Y. Chen 95 & 102.5 Kg Snatches
1999 Jr. Worlds (APAS Analysis)

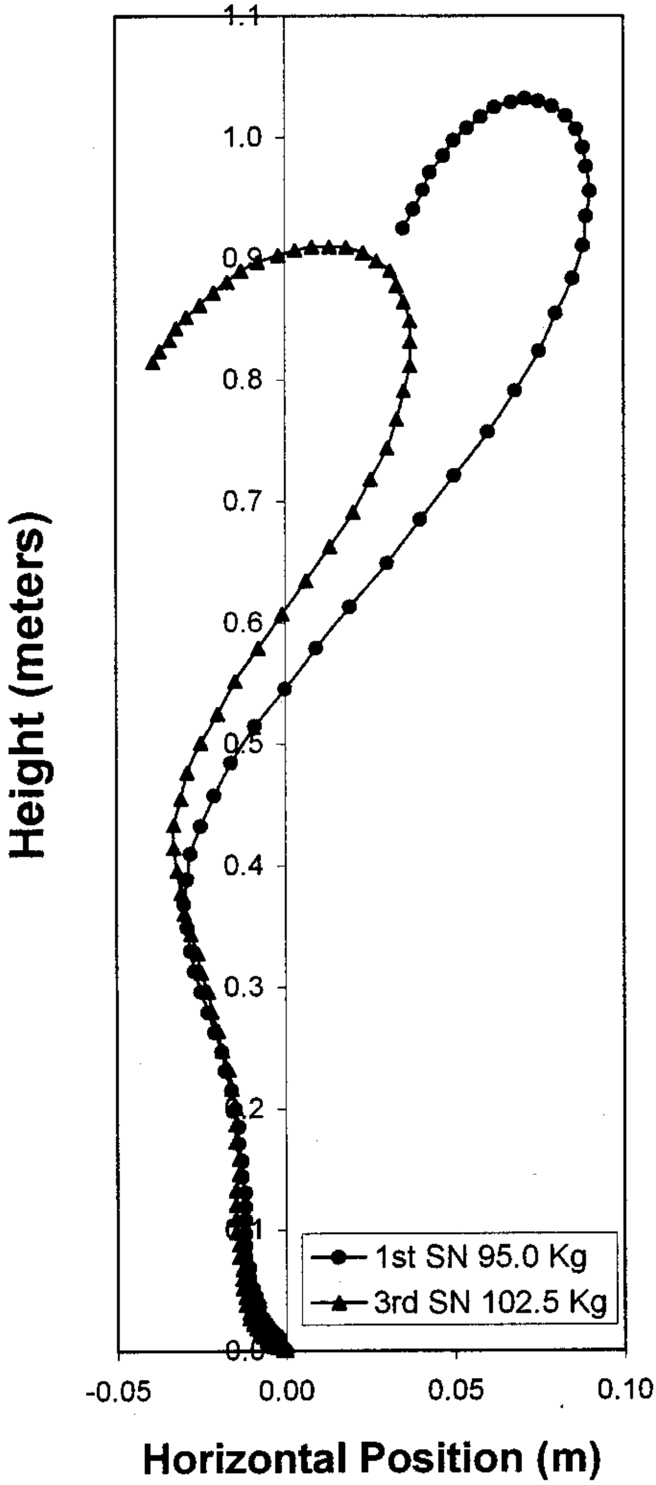

Figure 4: Z. Shi 142.5 & 150.0 Kg Snatches 1999 Jr. Worlds (Motus Analysis)