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A Biomechanical Analysis of Rowing

Proper coordination and sequencing of movements will result in efficient, powerful rowing. Joel Martin and Bryan St. Andrews explain.

By Joel R. Martin and Bryan St. Andrews Crossfit Nittany **December 2012**

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Similar to many movements encountered in CrossFit, rowing requires proper technique to maximize performance. Maintaining correct posture and properly sequencing leg, trunk and arm motion are important aspects of proper rowing technique.

Several research studies have been performed to characterize optimal rowing techniques (1,2,3,4). Most rowing experts agree that the proper sequence of motion—in order to maximize both stroke power and efficiency—is to start the row by driving the legs, then extending the hips, then pulling with the arms last. The majority of the stroke power comes from the legs and trunk (1). The greatest force exerted on the handle occurs in the first 40 percent of the row cycle (3).

Interestingly, the general coordination of the legs, torso and arms does not change with an increase in stroke rate. However, the arm-power contribution to the stroke and overall efficiency of the stroke does decrease with stroke rate (1). These findings suggest that the power developed in the legs and the sequencing of the leg drive to the trunk extension are the most crucial aspects of rowing. Failure to properly sequence motions can compromise how the spine is loaded (2), which may explain why low-back pain is common among elite rowers (4).

The purpose of this article is to present the findings from a small study performed at CrossFit Nittany, which quantitatively describes the rowing technique in several of its more experienced members and compares their data to that of a new member with little rowing experience. This was done to demonstrate how power is lost from improper sequencing of movements and poor posture. We will also discuss how the results from a biomechanical analysis can be extremely useful from a coaching standpoint.

Method

Four CrossFit Nittany members were videotaped while they completed a 2,000-meter row. Three of the members had been CrossFitting for more than six months, and one of the members was in the second week. The video was taken from the side, perpendicular to the rower. The video was then loaded into a motion-analysis software program so a 2D biomechanical analysis of each rower's stroke could be performed.

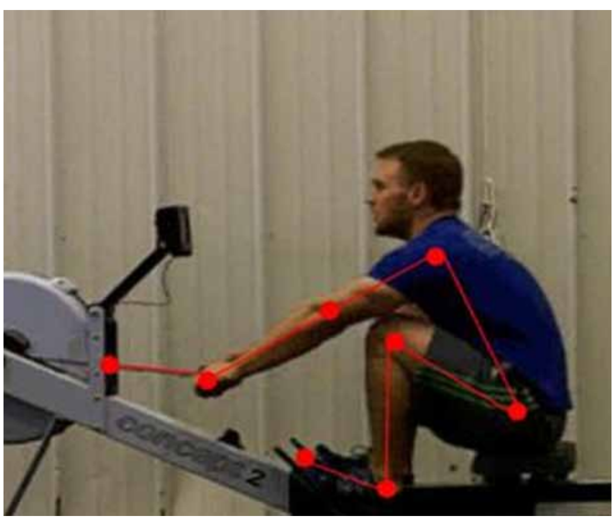

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Figure 1: Illustration of a biomechanical model created from a digitized frame of the rowing video.

In order to perform the analysis, the video had to be calibrated (calibration is the process of determining how long a known distance is in the video in terms of the number of pixels), and points of interest were digitized in each frame (digitization is simply going through each frame and clicking on certain points of interest). For our purposes, these points of interest were the end of the chain, the handle and the body joints on the left side of the person rowing (Figure 1). The software records the location of these points in the individual frames of video, and using the calibration data it is possible to obtain the X and Y locations (i.e., distances) of the points. In other words, the video frames are converted to a X-Y graph, and the locations of the digitized points can be measured using the calibration data. Once the locations of the points are found, angles between body segments can be obtained. Note: the torso angle was defined as the angle a line going from the hip to shoulder joint makes with a vertical line projected from the hips.

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This method of performing biomechanical analyses has been used in many other sports for years and can be a tremendous training tool, especially for elite athletes for whom a 1 percent improvement could mean the difference between winning a gold medal and not medaling at all. It is fundamentally the same technique as expensive motion-analysis systems in which reflective markers have to be placed on the points of interest, which has become a popular method of making video games and movies. Although the accuracy of such expensive systems may be better than the manual digitization of video, it is still possible to obtain quite accurate measurements through careful digitization of the video. The video-based method is also more friendly to the athletes as no markers need be placed on them, and it allows for movements to be analyzed during actual competition.

For the purposes of our study, we analyzed five strokes of each member, taken at various times over the 2,000-meter row. This allowed us to get a better feel of how one's technique may change as fatigue sets in, as well as natural variability from stroke to stroke. The joint angles and stroke length were measured for each frame, and velocities were calculated from that data. Basic statistical measurements were made on the data—means, minimums, maximums and ranges.

Results

1. "Catch" or Starting Posture and Final Posture

The average values of the lower-body joint and torso angle (relative to the vertical direction) for each athlete are shown in Table 1 and Table 2. The values in parentheses are minimum and maximum values from the five rows analyzed per athlete.

Rower 1 is the less-experienced athlete. Rowers 2, 3 and 4 have very similar values for all the angles. Rower 1 displayed similar values to the more experience values in terms of ankle and knee angle in the catch posture; however, the hip angle and torso angle were quite a bit different. The hips of Rower 1 were more open (larger angle) and the torso was more upright—essentially vertical. In terms of function, Rower 1's catch posture would most certainly limit the amount of power that can be produced through hip extension and the transfer of power from the legs to the arms as there is less range of motion through which the hips can extend during the row.

Rower	Ankle Angle	Knee Angle	Hip Angle	Torso Angle
1	69 (67,71)	37 (34,39)	52 (49,54)	2.5 (2,4)
2	75 (70,80)	60 (55,63)	30 (28,31)	30 (28,32)
3	72 (70,76)	57 (51,65)	32 (32,33)	24 (20,27)
4	67 (64,70)	40 (36,45)	27 (25,28)	23 (20,26)

Table 1: Average lower-body joint and torso angles for each of the athletes in the "catch" posture. The values in parentheses are the minimum and maximum values from the five trials analyzed.

The final angles of the rowers are given in Table 2. Again, all the values are fairly similar. Based on the final angle values and the initial angle values, Rower 1 goes through much less hip-extension motion. Also, Rower 3 goes through less motion at the ankles and knees than the other rowers. Interestingly, Rower 3 has less flexibility in these joints. This is a prime example of mobility issues limiting an athlete from performing efficiently.

Rower	Ankle Angle	Knee Angle	Hip Angle	Torso Angle
1	127 (124,130)	169 (167,170)	129 (126,132)	-29 (-31,-27)
2	127 (123,128)	162 (160,163)	144 (141,147)	-49 (-51,-46)
3	118 (114,121)	146 (142,152)	138 (132,144)	-51 (-54,-47)
4	133 (127,138)	174 (167,178)	138 (135,141)	-39 (-45,-34)

Table 2: Average lower-body joint and torso angles for each of the athletes in the final posture after the stroke is finished. The values in parentheses are the minimum and maximum values from the five trials analyzed.

2. Rowing Motion

The measures that directly translate to overall rowing performance are the power developed by each of the body segments, the coordination of these segments and the stroke length. Table 3 shows the average (range) of these values.

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The magnitudes of the knee, hip and elbow speed aren't as important as their sequencing, especially because the flywheel setting was different between the rowers. Ideally, there should be an increase in stroke speed as power is transferred from the knees to hips to arms. The more experienced rowers displayed this pattern while the less experienced rower showed a poor pattern of linking the knees to the hips. This is likely due to the poor catch posture, which limited the amount of power that could be transferred from the legs to hips before rowing even started.

Rower	Stroke Length (meters)	Max Knee Speed	Max Hip Speed	Elbow Speed
1	1.11 (1.10,1.13)	286 (273,298)	200 (183,210)	258 (226,295)
2	1.35 (1.34,1.36)	192 (185,203)	215 (196,233)	372 (341,403)
3	1.36 (1.32,1.45)	224 (188,247)	246 (222,266)	384 (356,408)
4	1.61 (1.56,1.64)	224 (209,233)	264 (240,314)	264 (240,314)

Table 3: Rowing performance measures. Knee, hip and elbow speed are in degrees per second.

Ultimately, the power produced by the rower needs to be transferred to the rowing machine. The speed of the stroke and stroke length are good indicators of this power transfer. Because the flywheel settings varied among the rowers, stroke speed is not a good measure to compare among the rowers.

Stroke length is a very good indicator of "bang for your buck" with each pull. Tall athletes are at an advantage because their height naturally creates longer stroke lengths. Rowers 1, 2 and 3 were all close to the same height (between 5'6" and 5'8"). Rower 4 was approximately 6'1" and thus naturally had a longer stroke length. Again, Rower 1 is rowing in an inefficient manner as the stroke length is quite a bit less than those of rowers 2 and 3 even though their heights are very close. This could be another side effect of the limited hip extension of Rower 1.

Comparison Between Proper and Improper Technique

To further illustrate the biomechanical differences in the sequencing of the rowing motion, we compared a less efficient rower (Rower 1) to an efficient rower (Rower 2). Rower 2 demonstrates an efficient movement pattern in which the knees reach their peak speed followed by the hips and finally arms (the dashed lines in Figure 2).

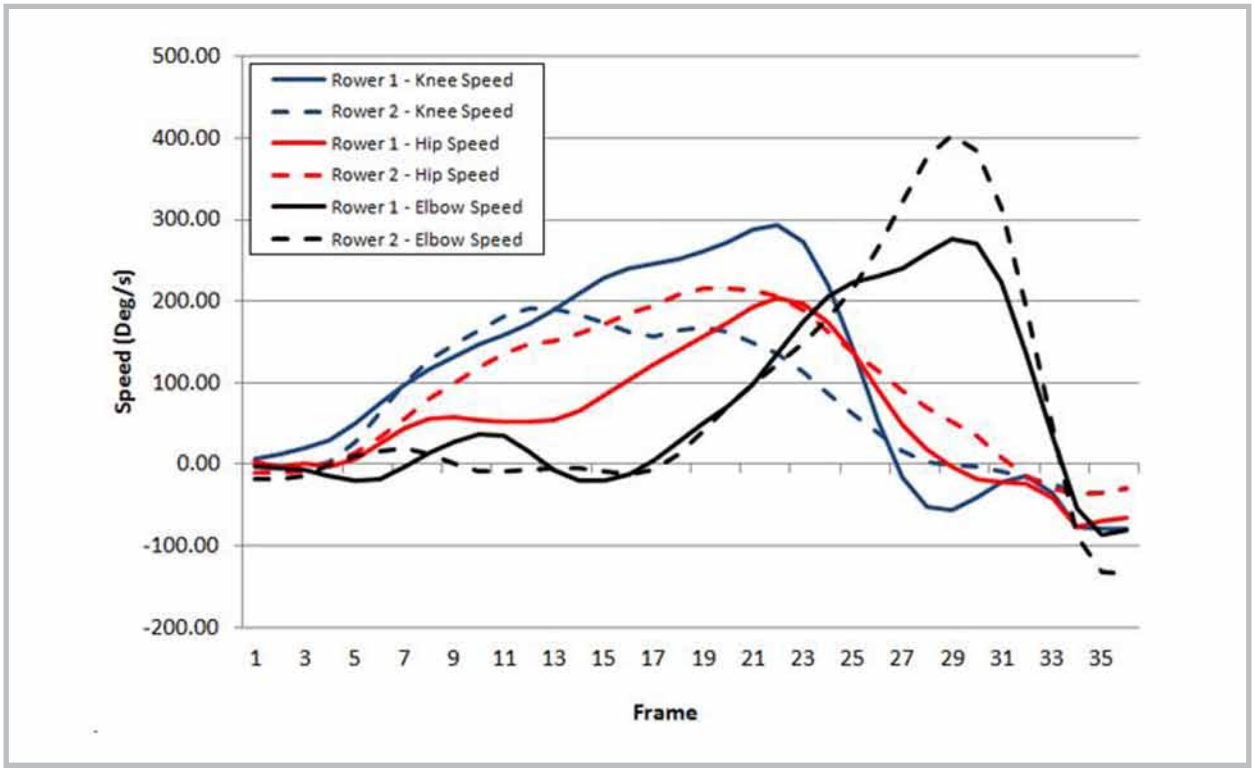

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Figure 2: Comparison of knee, hip and elbow speeds of a rower with poor coordination and sequencing of movements (solid lines) to a rower with a good sequencing of movements (dashed lines).

Notice that as soon as the previous segment began to slow down the next segment began to accelerate. This allowed the rower to keep increasing the pulling speed throughout the row, which is shown in Figure 3. Rower 1 displays a much less efficient rowing pattern (the solid lines in Figure 2). The knees and hips move together, with both peaking at approximately the same time. The hip speed is also quite a bit less than the knee speed, and the arms show a much more gradual increase to peak speed. The poor connection between the knees and hips undoubtedly is leading to a substantial "leakage" of power.

In order to show how poor coordination translates directly to rowing performance of one stroke, the stroke speed from the same stroke of Rower 1 and Rower 2 in Figure 2 was plotted in Figure 3.

First of all, keep in mind that the overall time for the stroke of each rower was the same—33 frames for each (the video was recorded at 30 frames per second, so the period is slightly over 1 second for the stroke). You can see that Rower 2 maintains a higher stroke speed for the majority of the stroke and continues to increase the speed all the way up to about Frame 25. Rower 1 initially increases the stroke speed at a lesser rate, and, more importantly, the stroke speed basically levels off midway through the stroke.

This study demonstrated how critical posture and coordination of different body segments are to rowing performance.

To no surprise, the middle portion of the stroke is where we would expect the transfer of power from the legs to hips as knee-extension speed decreases and hip-extension speed accelerates, which is exactly where Rower 1 displays issues.

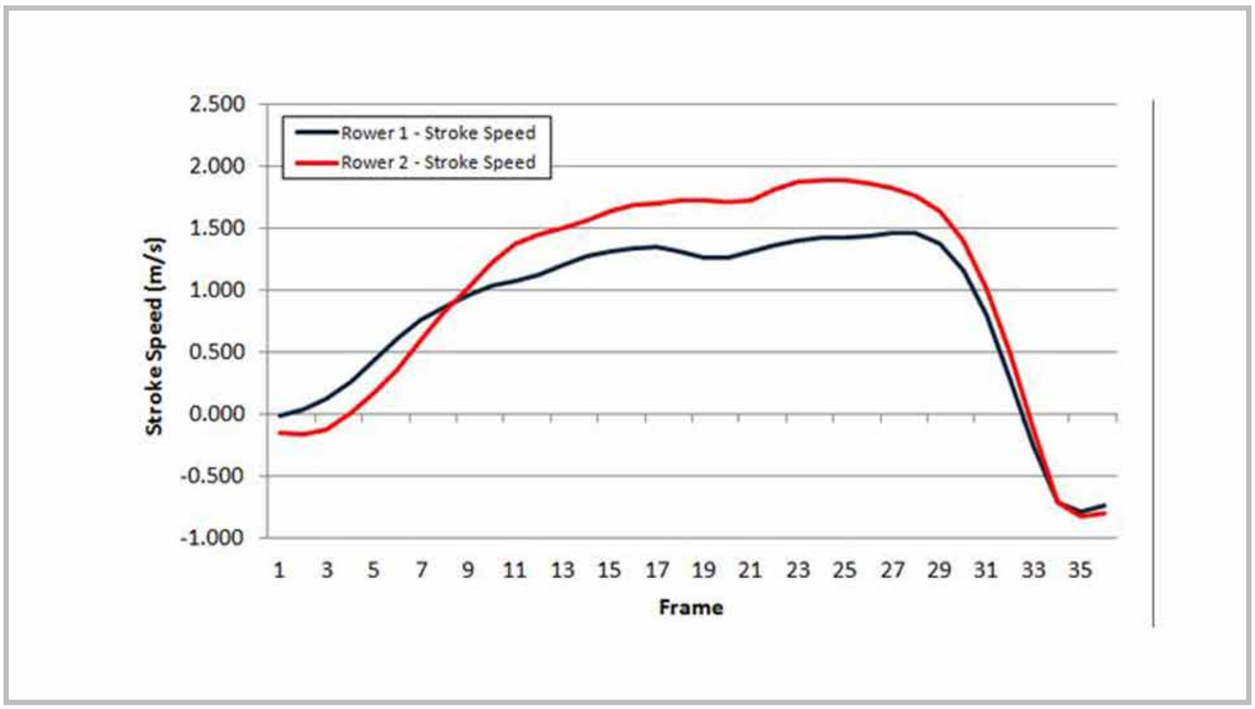

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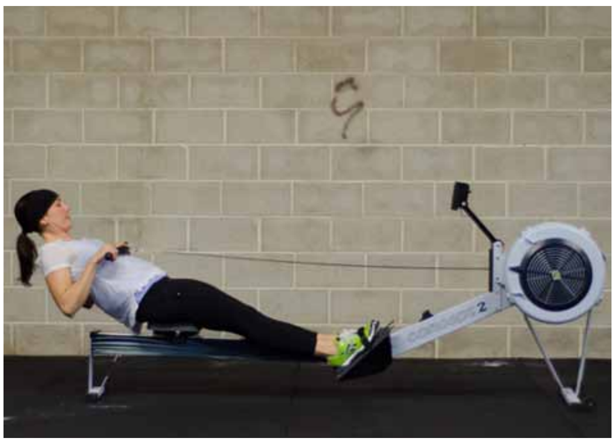
Figure 3: Stroke speed of a less experienced rower (Rower 1, in blue) and a more experienced rower (Rower 2, in red).

Fault: Early arm pull.

Fault: Early hip opening.



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Fault: Extreme layback.

Fault: Over-reaching in the catch.

Biomechanical model of proper sequencing: .mov .wmv

Summary

This study demonstrated how critical posture and coordination of different body segments are to rowing performance. Furthermore, poor starting posture may not allow one to properly coordinate a movement. This is true not only for rowing but for many other movements as well.

Ideally, an athlete should focus on correct posture and coordination before worrying about the actual values of things such as peak knee, hip and elbow speed. An in-depth biomechanical analysis of a movement, such as that performed in this study, may be extremely useful for elite CrossFitters looking to fine-tune their mechanics in various movements.

While most coaches might be able to correct errors in less skilled athletes using simple observations or even video recordings, it is often difficult to pinpoint errors in elite athletes who are performing many of the movements at very fast speeds. This type of biomechanical analysis not only provides a general qualitative description of how the athlete is performing the movement but also puts numbers to it.

In many cases, the only numbers that are used to describe how an athlete performs a movement are the weight lifted or the time to complete a movement or series of movements. Take, for example, the total time to complete a 500-meter row. However, the more important numbers—those which ultimately determine the weight lifted—are things like hip-extension speed or peak barbell velocity.

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In a sound stroke, coordinated movement of knees, hips and elbows—in that order—will produce the best results.

When it comes down to it, the goal of any movement is develop power in the muscles of the body and then transfer it between segments in order to exert force on an implement or surface, which may be the handle of a rowing machine, a barbell, a pull-up bar or the ground.

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About the Authors

Joel Martin just received his Ph.D. from Penn State in kinesiology. His research at Penn State under Dr. Vladimir Zatsiorsky focused on how the central nervous system controls movements. He has a strong interest in sports biomechanics and worked for several years for a company that specializes in performing 3D analyses of many different sports. Earlier this year, he traveled to the USA Track and Field Training facility in California to work with many of our Olympic athletes as they prepared for the London Olympics. Recently he started his own company, Rx Movement, which specializes in performing biomechanical analyses of any and all movements.

Bryan St. Andrews is the owner of CrossFit Nittany in State College, Pa., and has been involved with CrossFit since 2004. He currently has a B.S. in kinesiology from PSU, a master's degree from ASU, his CSCS certification and multiple CrossFit certificates. With strong ties to the Pennsylvania State University, Bryan is working to bridge the gap from the best practices employed in many CrossFit boxes to the academic world through research and application of scientific data.