SHOULDER ACTION DURING BOWLING

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Bowling to the casual observer appears to be a simple sport, having its object to tumble the highest number of pins with a rolling ball from a distance of 60 feet. The concealed complexity of the skill may be realized when an 1 degree deviation in the arm swing produces an error of 1 foot at the pins. The sport's complexity becomes more involved when considering the amount of pin and ball deflection produced as the ball collides with the pins.

As a result of the growing popularity of bowling in the amateur and professional ranks and the need for qualified instruction, the National Bowling Council (1974) and American Bowling Congress (1975; Ritger,1976) found it necessary to develop a standardized teaching methodology. Their models for teaching the arm swing were that the arm should resemble a free swinging pendulum, where the ball must gripped firmly and the movement initiated by pushing the ball away from the body. Then as the elbow reached maximum extension and was locked in place, the shoulder muscles should be relaxed thereby permitting a free pendular swing (Sabol, 1962). This action would permit gravity to serve as the motivating force in the arm swing and as the arm was moving through its free swinging pendular action the shoulder joint (pivot joint) would be translated down the lane with the bowler taking evenly spaced steps. During the steps of the approach just prior to the slidestep, the vertical position of the shoulder joint should undergo only minor vertical displacements with a large drop in shoulder height occurring during the slidestep and ball release (Ritger, 1976). The teaching model also states that a bowler should use as heavy a ball as he/she can control, in order to increase the pin deflection and reduce the ball deflection.

The purpose of this study was to examine the effects that different ball weights had on the kinetics and kinematics of the shoulder action during the bowling delivery of slow and high speed bowlers.

METHODS

All subjects were students in collegiate bowling classes and were screened by an average score range as cited by Martin (1960) for intermediate bowlers (135±12 pins) and an arm length of 26.5 to 28 inches. After passing the screening requirements, the bowlers rolled 6 warmup balls, followed by 5 trials during which the ball velocity was measured using a pair of laser timing gates separated by 1 foot and situated 6 feet from the foul line in the gutters of the bowling lane. The elapsed time between the photocell closures was recorded by a Berkley timer and the inverse of the time provided the actual ball velocity in feet per second. An average ball velocity was determined for the 5 trials and was used to categorize the subjects as high and slow speed bowlers using a 28.5 ft/sec criterion cut-off. Subjects were screened until 12 high and 12 slow speed bowlers were obtained.

Upon classification the subjects were randomly assigned to a treatment group sequence, representing the order of introduction of the varied ball weights (13, 15 and 17 lbs). A Brunswick Custom-matic bowling ball was utilized to provide adjustable grips and ball weights. A specially milled lead weight was inserted in the ball to make the ball weigh 17 pounds and be properly balanced. Each bowler rolled six trials per ball weight while trying to approximate his average velocity and the constant error from the criterion was reported to the bowler.

The bowling approach and deliveries of 24 bowlers were filmed using a 16 mm, pin-registered Photosonics camera operating at a framing rate of 76 fps. From a pilot study it was determined that by the 3^{th} or 4^{th} trial most bowlers were within 2% of their criterion velocity. Therefore only the 4^{th}, 5^{th}, and 6^{th} trials were filmed but the ball velocity measured by the laser timing gates was determined for trial and recorded. Only the trial that most closely approximated the criterion velocity for each ball weight was selected for film analysis. The film records were viewed with a Lafayette Analyzer using a rear projection system which magnified the film image 75X.

Data reduction was performed using a Numonics digitizing system interfaced with an Univac 1140 computer. Data points for the shoulder joint center, wrist joint center, the geometric center of the ball, and three reference markers were digitized for each film frame. Digitized coordinates were smoothed using a second-order recursive Butterworth filter with a cut-off frequency of 4 Hz. Appropriate calculations determining linear and angular displacements, velocities, accelerations, shoulder torques and impulses were performed on the coordinate information obtained from the cinematographic records. In order to examine the effect of particular variables during the bowling approach and delivery, the bowling movement was delineated into the following 3 phases: 1) pushaway to vertical arm position, 2) vertical arm position to height of backswing, and 3) height of backswing to ball release.

RESULTS AND DISCUSSION

Appropriate statistical designs were employed to analyze the selected variables of the slow and high speed bowling groups using an ANOVA. Average shoulder velocities were calculated over each of the three phases for the slow and high speed groups. A significant speed effect and phase effect was found to occur at the .05 level. Also from the analysis a nonsignificant ball weight effect was found. The slow speed bowlers accelerated their shoulder velocities from .01 m/sec during the first phase to 3.77 m/sec in the final phase (Table I). The high speed bowlers began at a velocity of .51 m/sec and their average shoulder velocity at release was 4.25 m/sec.

This may be interpreted that the slow speed bowlers pushed the ball out and allowed it to swing downward before taking a step forward, thus making the shoulder joint essentially a stationary pivot point. In contrast the high speed bowlers synchronized their step with the pushaway at the start of the movement. These velocities were slightly higher than the shoulder velocities reported by Murase (1974) and a great deal faster than the values found by Widule (1966). The difference between the shoulder velocities found in the present study and Murase's study, reflected the slower release velocities rolled by the their subjects. The speed differences between the present study and Widule's study may be explained by that study's method of determining a mean body velocity during the complete approach.

TABLE I

AVERAGE SHOULDER VELOCITY FOR THE THREE PHASES ACROSS THE BALL WEIGHT WEIGHT FACTOR

	Phase 1	Phase 2	Phase 3
SLOW SPEED GROUP	.01 ± .91m/sec (0.02 ft/sec)	1.09 ± .21m/sec (3.58 ft/sec)	3.77 ± .42m/sec (12.36 ft/sec)
HIGH SPEED GROUP	.51 ± .25m/sec (1.66 ft/sec)	1.26 ± .22m/sec (4.12 ft/sec)	4.25 ± .33m/sec (13.93 ft/sec)

The ball speed information reflected the changes in ball speed from trial to trial after the ball weight had been varied as the bowler attempted to attain his criterion velocity. These deviations in ball speed represented muscular alterations applied at the shoulder joint to accommodate the varied weight while still trying to maintain his target velocity. The ANOVA performed on the ball speed information found significant main effects for group membership, ball weight, and trial factors ($p \leq .05$). The significant speed effect was due to the use of the ball speed factor as a grouping factor. The ball weight effect could be interpreted that the weight of the ball had a significant influence on the speed of the ball rolled (Table II). A post-hoc analysis using a Scheffe test on the alterations in the ball speed found that significant differences existed between the legal (13 & 15 lbs) and the illegal weight balls (17 lbs). The significance of this contrast revealed that the setting of the 16 pound legal ball weight reflected for most bowlers a physiological limitation when attempting to maintain a criterion velocity.

An additional contrast using ball speed alterations was performed comparing the 15 lbs and 17 lbs ball speeds and found no significant difference to exist. This lack of significant difference was interpreted that a bowler could roll effectively a ball weighing more than the 16 lbs limit provided the ball represented only an 2 lbs increment above their preferred weight (Figure 1). The ability of a bowler to control a greater weight ball during the arm swing was reported by Sabol (1962) as resulting in greater pin fall.

TABLE II

RESULTANT BALL SPEEDS FOR DIFFERENT BALL WEIGHTS AND SPEED GROUPS

(Ft / Sec)

	Ball Weight (lbs) 13	15	17
SLOWSPEED GROUP	27.18 ± 1.24	26.94 ± 1.50	26.45 ± 1.51
HIGH SPEED GROUP	30.44 ± 1.75	29.51 ± 1.72	28.64 ± 1.67

The vertical displacement of the shoulder joint was calculated from the shoulder position at the start of the pushaway, to the bottom of the backswing, to the height of the backswing, and to the shoulder height at ball release during the slidestep. Fluctuations in the shoulder height indicated that the shoulder was not uniformly translated through the phases (Table III). A drop in the vertical height of .57 m was found during the slidestep phase and this fluctuation was expected since one of the functions of the movement was to decrease the shoulder height in order to produce a quiet ball release. Deviations in the first two phases reflected the effect of the ball's position during the arm swing on the shoulder position. A decrease of .31 m in the shoulder height was seen at the bottom of the arm swing due to the centrifugal forces of the arm and ball acting on the shoulder joint. An elevation of .22 m for the shoulder joint was determined at the height of the backswing. A significant ball speed by phase interaction was found to exist, indicating that the ball speed rolled influenced the vertical displacement of the shoulder (Figure 2).

The resultant ball velocity at release may have been produced by the following factors: 1) the speed of the approach (shoulder velocity), 2) the potential linear velocity due to the ball elevation, and 3) the muscular acceleration or deceleration of the shoulder during the delivery. Implied by the free swinging pendular model the ball speed at release should be derived from the sum of only the approach speed and the height of elevation of the ball with no muscular forces being applied to accelerate or decelerate the arm. A percentage representing a ratio between the sum of the approach velocity and potential linear velocity resulting from the arm swing and the final filmed horizontal velocity was calculated to determine the portion of the final velocity that was explained by the teaching model. A significant ball speed effect was found, with 90.8% and 87% of the final ball velocity being explained by the teaching model for the slow and high speed groups, respectively. The higher percentage found for the slow speed bowlers indicated that they permitted a more natural pendular arm swing to occur.

TABLE III

VERTICAL DISPLACEMENT OF THE SHOULDER DURING THREE COLLAPSING THE BALL SPEED AND WEIGHT FACTORS

	Phase 1	Phase 2	Phase 3
SLOW SPEED GROUP	$-.33\pm.23$ m (-1.08 ft)	$.24\pm.26$ m (.78 ft)	$-.62\pm.18$ m (-2.02 ft)
HIGH SPEED GROUP	$-.29\pm.16$ m (-.95 ft)	$.20\pm.21$ m (.65 ft)	$-.53\pm.14$ m (-1.74 ft)

Kinetic Relationships

Kinetic parameters were examined to determine the magnitude and timing of the maximum and minimum torques or force applications on the shoulder during each of the three phases. For the arm swing to represent a free swinging pendulum, the bowler would have to exert zero or near zero forces and resulting torques at the shoulder. From the film coordinate information the shoulder torques applied were calculated for each frame and then the values were plotted versus time. Also the computer program determined the magnitude and time of application of the maximum and minimum shoulder torques during each of the three phases. As the bowler faced the foul line and moved from left to right, a negative sign convention represented a clockwise rotation and a positive value indicated a counter-clockwise rotation. Additionally the area under the torque-time curve representing the shoulder impulses applied was determined.

The ANOVA performed on the peak shoulder torques found a significant phase ($p \leq .05$) but nonsignificance for the ball speed and ball weight factors. Therefore, an overall mean value collapsing the ball speed and ball weight factors for each of the three phases was calculated. A mean value of 6.09 ± 14.6 N.m was determined for the maximum shoulder torques which were applied at about 70% of the time elapsed during the phase (Table IV). This could be interpreted as the bowler hindering the arm descent from the pushaway to the vertical arm position (Figure 3.). During the backswing phase a mean peak torque of 16.6 ± 13.6 N.m was applied at approximately 25% of the second phase. Again, the bowler restrained the ball rise during the early portion of the backswing. A negative shoulder torque of -4.45 ± 11.1 N.m was calculated for the peak shoulder torques during the downswing phase and it was applied at about 50% of the interval. These negative torques were caused by the braking forces of the shoulder extensors used in an attempt to release the ball accurately at the bottom of the downswing (Figure 3).

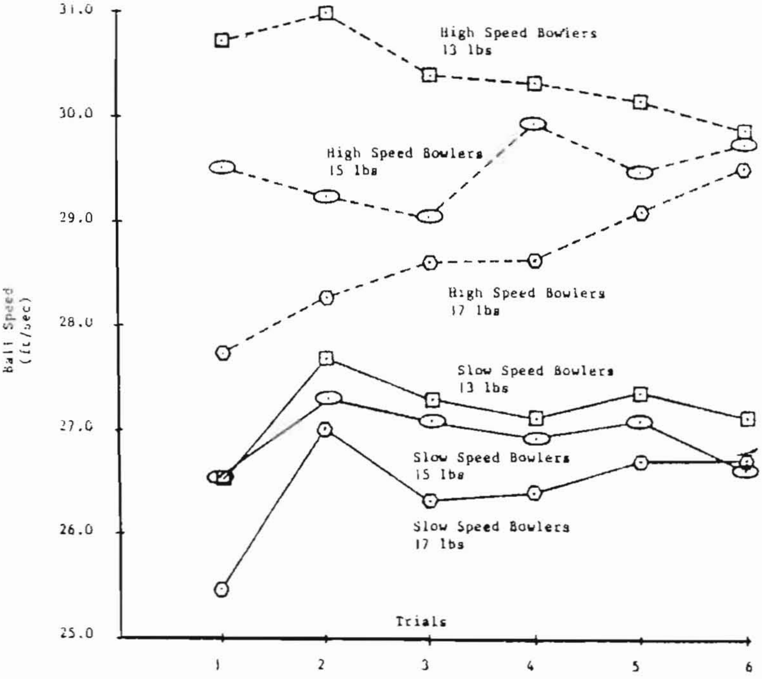

Figure 1. Ball speed versus trials for different speed and weight groups.

The minimum shoulder torques represented the largest shoulder torques producing a clockwise rotation during each of the three phases. The ANOVA found a significant phase effect and phase by speed group interaction. Negative minimum shoulder torque values of -42.2 ± 47.2 N.m and -25.4 ± 13.0 N.m were found for the slow and high speed bowlers in the pushaway phase. The slow speed bowlers applied their accelerative torque at 11% of the interval while the high speed bowlers applied their minimum torques at 9 % through the pushaway phase. During the second phase, negative minimum shoulder torque values of -19.8 ± 12.8 N.m and -31.55 ± 17.9 N.m were calculated for the slow and high speed bowlers. Their respective times of application were 81.2% and 82.8% through the backswing phase. The negative value indicated that the bowlers lifted the ball during the backswing with the high speed bowlers applying more muscular force. For the final phase (downswing), the minimum shoulder torques were -71.7 ± 20.9 N.m and -79.9 ± 30.5 N.m for the slow and high speed bowlers, respectively. These large negative torques indicated that both groups applied decelerating shoulder torques during the downswing. It should be noted that only during the downswing phase were negative values determined for the maximum and minimum shoulder torques, indicating a controlled descent of the arm during the downswing (Figure 3). During the pushaway and backswing phases, torque values of different signs were calculated for the maximum and minimum shoulder torques which indicated that the bowlers muscularly accelerated and decelerated their arm during the same phase.

The ANOVA found that the impulses applied at the shoulder varied from phase to phase but no significant speed group or ball weight effects were found. Therefore a one sample t-test was performed on the shoulder impulse information for each phase in order to determine if the shoulder impulses exerted during each delivery phase were equal to zero. The statistical analysis revealed that only during the second phases did the bowlers apply zero shoulder impulses, whereas during the initial

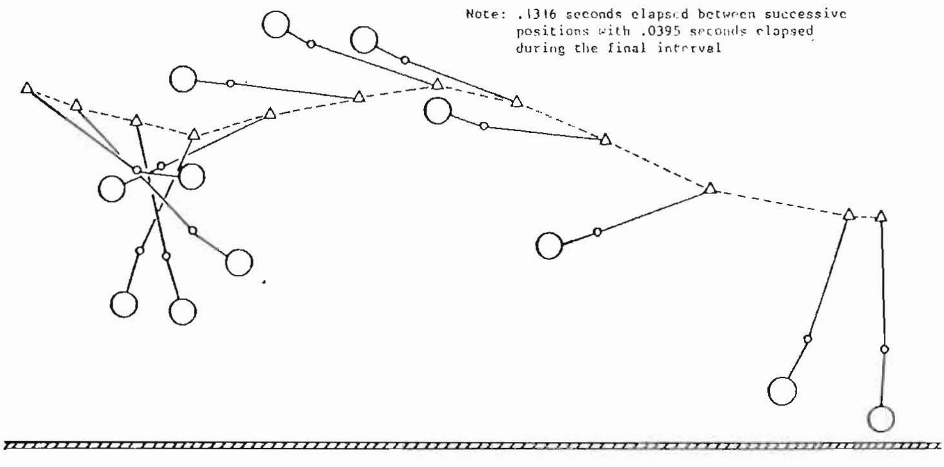

Figure 2. A typical shoulder action for a slow speed ball.

and final phases, muscular forces were applied at the shoulder. Substantial negative shoulder impulses were found to occur during the downswing phase and these findings were consistent with the sign of the torque values applied during this phase and this would suggest that the bowlers decelerated their arm prior to ball release (Tables IV & V). Therefore the arm swing employed by the intermediate bowlers tested, represented a free pendular action only during the second phase (latter portion of the backswing).

TABLE IV
MEAN MAXIMUM AND MINIMUM SHOULDER TORQUE IN N.M

		Phase 1	Phase 2	Phase 3
SLOW SPEED BOWLERS	Min	-42.2±47.2 (11.2%)	-19.8±12.8 (81.2%)	-71.7±20.9 (98.6%)
	Max	5.9±19.8 (62.0%)	13.7±14.7 (23.2%)	-5.0± 7.8 (50.6%)
HIGH SPEED BOWLERS	Min	-25.4±13.0 (9.2%)	-31.4±17.9 (82.8%)	-79.9±30.5 (86.7%)
	Max	6.3± 9.3 (76.8%)	19.4±12.4 (28.0%)	-3.9±14.4 (57.3%)

Note: Values in parentheses represent the percentage of the phase when torque was applied

TABLE V
PHASE BY BALL WEIGHT FOR SHOULDER IMPULSES COLLAPSING THE SPEED GROUPING DIMENSION IN N.M/s

	Ball Weight 13	15	17
PHASE 1	-3.0 ± 6.1	-1.8 ± 2.7	-3.2 ± 3.8
PHASE 2	0.6 ± 5.0	-1.2 ± 5.3	-2.4 ± 4.9
PHASE 3	-9.7 ± 3.4	-11.3 ± 4.2	-12.6 ± 3.6

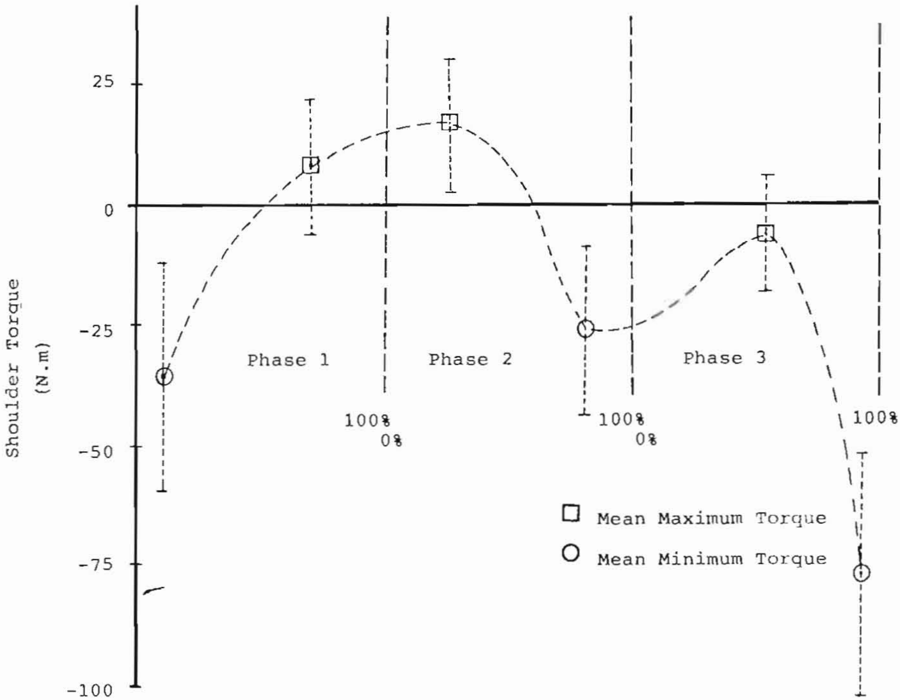

Figure 3. Mean maximum and minimum shoulder torque and time of application

CONCLUSIONS

From the findings of this study the following conclusions appear to be justified:

1) Intermediate bowlers progressively increased their average shoulder velocity as they moved through the pushaway, backswing, and downswing phases. Therefore, the bowling approach can not be accurately described as a cadenced movement down the lane. High speed bowlers derived greater horizontal velocity from their approach than slow speed bowlers.

2) Ball weight influenced the resultant ball speed. Bowlers more closely approximated their criterion velocity when they used legal weight balls (13 & 15 lbs) than the illegal weight ball (17 lbs). The bowlers could maintain their criterion velocity when the ball weight was varied in increments of 2 lbs or less.

3) The vertical position of the shoulder was decreased during the pushaway and downswing, and elevated in the backswing phase. The ball speed rolled and arm position (phase) uniquely influenced the vertical height of the shoulder.

4) Different maximum and minimum shoulder torques were applied from phase to phase by both speed groups. The bowlers exerted decelerative muscular forces during the latter portion of the downswing and early portion of the backswing corresponding to the arm being at the bottom of the arm swing. High speed bowlers applied greater accelerative shoulder torques than the slow speed bowlers to facilitate the ball lift in the backswing.

5) Non-zero shoulder impulses were applied at the shoulder during the pushaway and downswing phases. The arm swing employed during the delivery by the intermediate bowlers should be described as an accelerated pendulum rather than a simple free-swinging pendulum.

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