SKILL LEVEL CHANGES OF SEGMENTAL CONTRLBUTIONS TO BALL VELOCITY IN THE OVERHAND THROW

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INTRODUCTION

Overhand throwing is a skill common to many sports. Most of the recent research regarding throwing has focused on baseball pitching. While not identical, pitching and overhand throwing motions are similar in mechanics and purpose- to achieve maximum velocity at the distal end of the upper extremity. Through the use of sequential segmental motions, the principal actions of the upper extremity can achieve large rotational velocities, thus yielding similarly large ball velocities at release (Elliott, Takahashi, & Marshall, 1996; Gowan, Jobe, Tibone, Perry, & Moynes, 1987; Pappas, Zawacki, & Sullivan, 1985). Sequential segmental motions produce velocity at the distal end by initiating each successive segment when the previous segment has reached peak velocity (Miller, 1980).

While much is known about the techniques used by highly skilled performers to achieve large throwing velocities, little is known about how the segments contribute to ball velocity. Moreover, even less is known about how technique and segment contributions differ across skill levels of developmentally mature throwers. In one study, Gowan et al. (1987) compared less-skilled (amateur) pitchers to more-skilled (professional) pitchers. They found the less-skilled pitchers used the biceps brachii and more rotator cuff muscles than more-skilled pitchers, who primarily used the subscapularis, in the acceleration phase of the pitch. Overall, activation patterns of the upper extremity muscles were similar between both skill levels. In a study of the tennis power serve, Elliott, et al. (1995) found trunk rotation and translation provided greater relative contribution in the serves of high-performance tennis players than in the performances of tennis players in previous studies.

It is not known whether trunk rotation and translation affect the overhand throw in a similar manner. Additionally, it is not known whether the legs, arm, and hand contributions differ among throwers of different skill levels. The purpose of this study was to examine the relative contribution of the legs, trunk, arm, and hand to overhand throwing velocity across several skill levels.

METHODS

One hundred and one subjects participated in this study. All subjects were athletes currently or formerly involved in activities that required overhand throwing motions. Seven subjects who exhibited a "push" in their throwing technique were eliminated. The 94 remaining subjects all exhibited developmentally mature patterns (75 male, 19 female, 86 right-handed, 8 left-handed, mean age 22.6± 2.4 years).

To determine the contribution of the selected segments to throwing velocity, all subjects randomly performed four different maximal throws. These four throwing conditions were based on previous work by Toyoshima, Hoshikawa, Miyashita, & Oguri (1974). In one throwing condition, the subjects performed a normal overhand throw using the whole body (WBT). Subjects were only allowed one step in performing this throw. In another throw, the subjects performed with both feet slightly staggered, but remaining in fixed positions (NLT). This throw eliminated leg contribution, but allowed the trunk, arm, and hand to follow typical throwing motions. A third condition required a throw with both the leg and trunk contributions eliminated (NTT). This throw was performed with the subject seated and the trunk strapped to prevent movement. The arm and hand were able to follow typical throwing motions. The fourth throwing condition allowed only wrist contribution (WRT). This throw was performed with the subject standing, arm abducted to the horizontal, and forearm flexed to a 90 degree angle to the arm. The forearm was strapped to a plate that only allowed wrist flexion and extension.

After receiving informed consent from each subject, he or she warmed up and stretched to preferred levels. Each subject then randomly performed the four throws into a net with a target approximately five meters distant. All subjects threw standard baseballs (mass = 143g, diameter = 7.6cm). Each throwing condition was performed until a minimum of three acceptable throws were recorded. Most subjects required between three and five throws for each condition. A radar gun was used to measure the ball velocity at release for all throws. The target was situated within the "window" of the radar gun and helped minimize the number of throws needed.

For each throwing condition, the average velocity of all acceptable throws was used. The relative contribution of the legs (LEG%), trunk (TRNK%), and arm (ARM%, which included shoulder and elbow joints) were estimated from differences between the previously described throws. The WRT throw condition was a direct estimate of the hand contribution (HAND%, which included wrist and finger joints). All contributions were relative to the WBT. The equations used were:

LEG% = (WBT - NLT) / WBT
TRNK% = (NLT - NTT) / WBT
ARM% = (NTT - WRT) / WBT
HAND% = WRT / WBT

RESULTS

Initially, a MANOVA was used to compare the performance of the males and females. No significant differences were found ($p > 0.05$). After combining the males and females into one group, all subjects were then separated into three groups based on percentile score for the WBT. This resulted in a low velocity group (n=32), a medium velocity group (n=30), and a high velocity group (n=32).

One way ANOVAs (df=2,91) were used to compare the relative contributions between the groups. Significant differences ($p<0.05$) existed between groups for all four relative contributions. ScheffÈ post-hoc tests revealed the high velocity group had significantly greater relative leg contribution than the low velocity group. The high velocity group also had significantly greater relative trunk contribution than both the medium and low velocity groups. For relative arm contribution, however, the high velocity group had significantly less contribution than the low velocity group. For relative hand contribution both the high velocity and the medium velocity group had significantly less contribution than the low velocity group. See Table 1 for descriptive values.

Table 1. Mean (±S.D.) relative contribution for the segments. An * indicates a significant difference between high velocity and low velocity groups, a ‡ indicates a significant difference between the high velocity and the medium velocity groups, and a § indicates a significant difference between the low velocity and the medium velocity groups.

GROUP	LEG%*	TRNK*‡	ARM%*	HAND%*§	WBT
LOW VELOCITY	12% (±4.70)	24% (k4.82)	43% (±4.25)	21% (k2.91)	22 m/s (32.98)
MEDIUM VELOCITY	14% (±2.69)	25% (k3.84)	42% (f3.24)	20% (±2.31)	27 m/s (±0.94)
HIGH VELOCITY	15% (±4.23)	27% (k4.39)	40% (±3.75)	18% (k2.12)	31 m/s (±1.77)
ALL SUBJECTS	13% (f4.19)	25% (±4.58)	42% (f3.95)	20% (±2.83)	26 m/s (k4.39)
P-VALUE	0.007	0.007	0.006	0.000	N/A

DISCUSSION

The estimated relative contribution of the legs, trunk, arm, and hand appears to differ among throwers of different skill levels. The values obtained for the throwers' WBT were similar to or slightly lower (ranging from 16.83m/s to 35.16m/s, mean: 26.79m/s) than those found in pitching studies (means ranging from 25.26m/s to 33.5m/s) (Feltner, 1989; Gowan et al., 1987). Reliability of the data was indicated by the consistent performance of the subjects. Typically, when additional throws were required it was because the ball failed to move through the proper "window" needed by the radar gun. Most subjects performed each condition with the minimum three throws and rarely required more than five. It is likely that maximal overhand throwing is as consistent as pitching (Feltner, 1989; Pappas et al., 1985).

The legs and trunk together contributed about 39% of throwing velocity for all subjects in this study. Generally, both the contribution of the legs and the contribution of the trunk increased as ball velocity increased. (Figure 1.) Broer (1969) proposed that the legs and trunk would provide about 50% of throwing velocity. Toyoshima et al. (1974) found the legs contributed 46.9% to throwing velocity in their study. The legs and trunk are important because they provide velocity from translation and long-axis rotation. The powerful muscles within these segments provide the force necessary to overcome inertia and begin the "whip-like" action that results in maximum velocity at the distal end of the arm.

The arm and hand together contributed about 61% of throwing velocity for all subjects in this study. Generally, both the contribution of the arm and the contribution of the hand decreased as ball velocity increased. (Figure 1.) The purpose of the arm and hand segments is to add to the velocity generated by previous segments. In a coordinated movement, the arm would begin motion at the peak velocity of the trunk and the hand would begin at the peak velocity of the arm. It appears the arm experiences a "ceiling effect" as throwing velocity increases. The lack of increased speed in proportion to the leg and trunk segments may be due to strength and power limitations, the inability to provide the torque necessary for additional velocity, or the inability of the musculature to contract at greater speed.

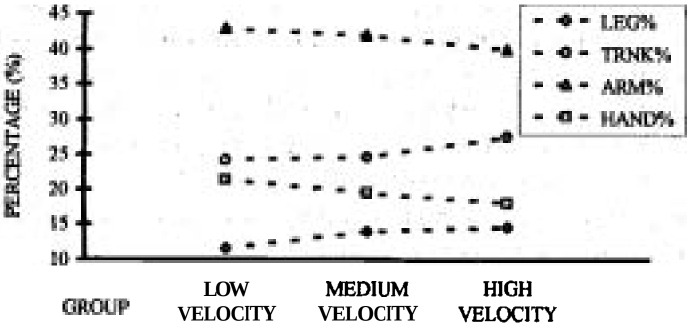

Figure 1. Relative contribution of segments by group.

Each of the segments are capable of producing velocity in multiple ways. The legs add to throwing velocity by actions at the ankle, knee, and hip providing thrust and by long-axis rotation at the hip. The trunk adds to throwing velocity by flexion and long-axis rotation. The arm adds to throwing velocity in the most complex manner, using medial rotation, transverse adduction, small amounts of abduction and adduction, and elbow extension. While the elbow is not an irrelevant contributor to throwing velocity, it has not been found to be a great influence on throwing velocity (Feltner, 1989; Toyoshima et al., 1974) and would have added complexity to the data collection methods used. The hand segment adds to throwing velocity by flexion at the wrist and fingers. It is not surprising the arm contributes a large share to ball velocity given the importance of long-axis rotations to throwing velocity (Elliott et al., 1996). Furthermore, based on the summation principle, long-axis rotations of both the trunk and hip might be as important to arm long-axis rotations as any other factor.

All subjects were able to demonstrate greater velocities in later segments than they were in earlier segments. While factors such as muscle fiber type, strength, and subject's prior experience influence the product, the differences in segmental contribution found were more a function of technique differences between throwers. Even though the values presented are just segmental contributions estimates, the differences among skill levels should hold under more sophisticated analysis.

The advantage in the present data collection method is ease of use. With simple data collection and reduction tools, any practitioner could collect data using similar methods. There may be implications regarding injury prevention and skill instruction. If less-skilled throwers tend to use arm muscles unnecessarily and more-skilled throwers tend to use the arms more effectively, then better technique will lead to improved endurance and reduced overuse injuries (Glousman, 1993). Teachers and coaches can benefit not only from the data they may collect on athletes, but on the instructional methods they may use based on these results. If proper use of the lower extremity and trunk is emphasized during instruction about the mechanics of an athlete's throw, greater velocities may be produced. Also, conditioning programs should emphasize the muscles of the lower extremity and trunk as much as the upper extremity.

CONCLUSIONS

While joint immobilization methods are beneficial for general insights regarding segmental contributions (Miller, 1980), there is a need for more sophisticated three-dimensional methods to verify the differences among skill levels found in this study. Recent advances in methodology may allow reasonably accurate estimates of joint contributions using three-dimensional analysis (Elliott et al., 1995). Such studies will verify how segmental contributions differ with skill level and whether less sophisticated methods overestimate or underestimate these contributions.

In general, it was found that as ball velocity increased the relative contribution of the legs and trunk increased, while the relative contribution of the arm and hand decreased. While factors such as muscle fiber type, strength, and experience are important in throwing performance, it seems that technique differences with respect to leg, trunk, arm, and hand segment contributions affect throwing speed. Perhaps arm and hand velocity contributions are limited by a ceiling effect and the legs and trunk are not. It appears better throwers generate velocity more from the legs and trunk, which generate velocity with long axis rotation and translation of the entire body, than from the arm and hand.

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