Gluteal Muscle Group Activation and Its Relationship With Pelvis and Torso Kinematics in High-School Baseball Pitchers

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ABSTRACT

Oliver, GD and Keeley, DW. Gluteal muscle group activation and its relationship with pelvis and torso kinematics in high-school baseball pitchers. J Strength Cond Res 24(11): 3015–3022, 2010—The purpose of this study was to examine the activation patterns of the gluteal muscle group and their relationship to pelvis and torso kinematics throughout the high-school pitching motion. A single group, repeated-measures design was used to collect gluteus maximus and gluteus medius muscle activity through surface electromyography for the preferred and nonpreferred sides during the various phases of the pitching motion. In addition, data describing the kinematics of the pelvis and torso were collected at foot contact, maximum shoulder external rotation, ball release, and maximum shoulder internal rotation. For all pitchers, preferred gluteus maximus activity was observed to be in excess of 100% of their maximum voluntary isometric contraction throughout the stride and arm-cocking phases of the pitching motion. The observed means for the preferred gluteus medius, nonpreferred gluteus maximus, and nonpreferred gluteus medius, although different in magnitude, were similar in pattern. From the conclusion of the stride phase, through the conclusion of the arm-cocking phase, muscle activity increased for all pitchers. In examining the relationship between the rate of axial pelvis rotation and gluteal activity, several significant relationships were observed. In contrast, no significant relationships were observed with gluteal activity parameters and the rate of axial torso rotation. However, because the pitching motion progresses sequentially from the pelvis to the torso, variability in pelvis rotation may be directly related to variability in torso rotation. The findings from this study indicate that during the baseball pitch, there is a need for greater control of gluteal activation throughout the pitching motion.

KEY WORDS electromyography, kinetic chain, overhead throwing

INTRODUCTION

It has become evident in the literature that control of the pelvis and torso plays a major role in not only athletic performance but also in injury prevention (7,22,31,32). Core stability is critical in allowing for optimal transfer of forces generated from the lower extremity to the upper extremity (26). It has been defined by Pope and Panjabi (24) that core stability is the function of the lumbopelvic-hip complex to both prevent collapse of the vertebral column and return it to natural stability. When discussing the lumbopelvic-hip complex, we include the gluteal muscle group.

As described by Baechle et al. (4), Kibler et al. (18), and Putnam (26), it is the premise that the core, or lumbopelvic-hip complex, essentially allows proximal stability for distal mobility. Structurally, the lumbopelvic-hip complex is the area encompassing the pelvis and supporting the torso. The foundation of stability for the pelvis is fundamentally supplied through activity in the gluteal muscle group. The gluteal muscle group acts to stabilize the torso over a leg that is planted and allows for transference of power for any forward leg movements (25,26,30,32).

From a functional biomechanics perspective, Putnam (26) described the appropriate timing and momentum of the larger more proximal segments (trunk) as being summated by the speed principle. Essentially, a segment initiates its movement when the adjacent proximal segment reaches its maximum angular velocity (e.g., the shoulder reaches its maximum angular velocity just before the elbow reaching its maximum angular velocity). When examining activities such as kicking, jumping, and the tennis serve, the pelvis and torso segments have been shown to have the largest contribution to the body’s total angular momentum (5,8,25). Similarly, these segments have been shown to contribute approximately 50% of the kinetic energy during the act of throwing (29).

In baseball, many studies have examined the upper extremity and the stresses about the shoulder (1,3,9–11,30), whereas others have focused on the lower extremity (19,20). In investigating pelvis and torso kinematics, it has been found that lower values of lumbar flexion and rotation are indicative of a more open torso position during the pitch (22), and that decreases in forward trunk tilt result in pitchers throwing with a more upright posture (9). Unfortunately, the manner...
in which the kinematics of these segments may be affected by core, or the true lumbopelvic-hip complex activity, has yet to be thoroughly researched. Furthermore, it is not currently known as to what role the gluteal muscle group plays with the movements of the pelvis or torso throughout the pitch cycle. Thus, it was the purpose of our study to examine the activation patterns of the gluteal muscle group and their relationship with pelvis and trunk kinematics during the pitching motion of high-school baseball pitchers. It was hypothesized that the observed patterns of gluteal activation would be significantly related to the kinematics of the trunk and pelvis and that the nature of those relationships would be dependent on the function of each individual gluteal muscle.

METHODS

Experimental Approach to the Problem

A single group, repeated-measures design was used to collect gluteus maximus and gluteus medius muscle activity for both the preferred and nonpreferred legs throughout the stride, arm-cocking, arm acceleration, and arm deceleration phases of the pitching motion. In addition, data describing the kinematics of the pelvis and torso were collected at the points of foot contact, maximum shoulder external rotation, ball release, and maximum shoulder internal rotation. The data in the current study were collected in a manner such that subjects threw a series of maximal effort fastballs to a catcher located the regulation distance from the pitching mound (18.44 m) and those data from the fastest pitch passing through the strike zone were analyzed (15,27). Subsequent to data collection, both surface electromyographic (sEMG) and kinematic data were analyzed using a series of descriptive statistics to identify outliers and determine the nature of the distribution before testing for the presence of relationships. The nature of the distribution was analyzed using the Shapiro–Wilk statistic (W-statistic, p > 0.05).

Once the data were deemed to be normally distributed, testing for relationships was conducted by calculating the Pearson product moment correlation coefficients to examine the relationship between gluteal activity and both pelvis and torso kinematics. In the current design, electromyographic data were the independent variables, whereas the kinematic data describing torso and pelvis kinematics were the dependent variables. These variable assignments are consistent with the opinion that because the pitching motion can be viewed as the sequential activation of body segment through

<table>
<thead>
<tr>
<th>Body segment</th>
<th>Axis about which rotation was performed</th>
<th>Resulting angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvis</td>
<td>First rotation</td>
<td>Flexion (−)/extension (+)</td>
</tr>
<tr>
<td></td>
<td>Second rotation</td>
<td>Left lateral tilt (−)/right lateral tilt (+)</td>
</tr>
<tr>
<td></td>
<td>Third rotation</td>
<td>Right axial rotation (−)/left axial rotation (+)</td>
</tr>
<tr>
<td>Thorax</td>
<td>First rotation</td>
<td>Flexion (−)/extension (+)</td>
</tr>
<tr>
<td></td>
<td>Second rotation</td>
<td>Left lateral tilt (−)/right lateral tilt (+)</td>
</tr>
<tr>
<td></td>
<td>Third rotation</td>
<td>Right axial rotation (−)/left axial rotation (+)</td>
</tr>
</tbody>
</table>

*Prime (’) and double prime (’’) notations are used to represent previously rotated axes. Each time the local coordinate system is rotated, all axes within that system are rotated (i.e., − When an initial rotation occurs about the Z-axis, both the Y-axis and Z-axis are also rotated producing 3 new axes; X’, Y’, and Z’. Subsequent rotations will then be about these axes.)
a linked system, alterations in gluteal activity throughout the pitching motion may result in changes to pelvis and/or torso kinematics.

Subjects
Twelve high-school male pitchers (age: 16.3 ± 1.1 years; height: 176.6 ± 7.8 cm; and mass: 76.4 ± 7.4 kg) regardless of throwing arm dominance volunteered to participate in the current study. All subjects had recently completed their competitive spring baseball seasons and were thus deemed appropriately conditioned for competition. Additional criterion for participation included recommendation of their respective coaching staff, multiple years (up through the current season) of pitching experience, and freedom from injury throughout the current baseball season.

Data collection sessions were conducted indoors at the University of Arkansas Health, Physical Education, and Recreation building and were designed to best simulate a competitive setting. All testing protocols used in the current study were approved by the University of Arkansas Institutional Review Board, and before participation, the approved procedures, risks, and benefits were explained to all subjects and their parents who then signed the appropriate paperwork to provide consent for testing.

Procedures
Subjects reported for testing before engaging in resistance training or any vigorous activity that day. Location of right and left gluteus maximus and right and left gluteus medius was identified through palpation. Before testing, the identified locations for surface electrode placement were shaved, abraded, and cleaned using standard medical alcohol swabs. Subsequent to surface preparation, adhesive 3M Red-Dot bipolar surface electrodes (3M, St. Paul, MN) were attached over the muscle bellies and positioned parallel to muscle fibers using techniques described by Basmajian and Deluca (6). In the current study, the selected interelectrode distance was 25 mm (16). Surface electrodes were used because they have been deemed to be a noninvasive technique that is able to reliably detect surface muscle activity (6,14,16).

To transmit sEMG data to The MotionMonitor™ motion capture system (Innovative Sports Training Inc, Chicago IL), a Myopac Jr 10-channel amplifier with a common mode rejection ratio equal to 90 dB and set at a gain of 2,000 (RUN Technologies Scientific Systems, Laguna Hills, CA) was employed. Throughout all testing, sEMG data were sampled at a rate equal to 1,000 Hz. Filtering of all sEMG data was completed using standard band-pass filtering techniques with band-pass filters set at cutoffs of 20 and 350 Hz, respectively. Additionally, all sEMG data were notch filtered at frequencies of 59.5 and 60.5 Hz, respectively (7).

Once all electrodes had been secured, 3 manual muscle tests (MMT) were conducted for each muscle. These MMTs were conducted using techniques described by Kendall et al. (16) and used to identify the approximate maximum voluntary isometric contraction (MVIC) for each muscle. All MMTs consisted of a 5-second isometric contraction for each muscle, with the first and last seconds of each contraction removed so as to obtain steady state results. Each MMT was
conducted to establish baseline readings for each participant's maximum muscle activity to which all sEMG data could be compared. Before MMT conduction, the approved testing protocol was explained to all subjects to ensure their full understanding.

In addition to sEMG data, kinematic data describing the movements of the pelvis and torso were collected throughout the phases of the pitching motion. Kinematic data were collected using The MotionMonitor™ motion capture system (Innovative Sports Training, Chicago IL). Before completing test trials, subjects had a series of electromagnetic sensors attached to the medial aspect of the torso and pelvis at the C7 and S1 locations, respectively (21). Sensors were affixed using double sided-tape and then wrapped using flexible hypoallergenic athletic tape (Figure 1). After the attachment of the electromagnetic sensors, a third sensor was attached to a stylus and used to digitize the palpated position of various bony landmarks (23). To accurately digitize the selected bony landmarks, subjects stood in the neutral anatomical position while digitization was being completed.

Throwing kinematics for right-handed subjects were calculated using the standards and conventions for reporting joint motion recommended by the International Shoulder Group of the International Society of Biomechanics (33,34). Raw data describing sensor orientation and position were transformed to locally based coordinate systems for each of the respective body segments. Euler angle decomposition sequences were used to describe the position and orientation of the both the pelvis and trunk relative to the global coordinate system (33,34). The use of these rotational sequences allowed the data to be described in a manner that most closely represented the clinical definitions for the movements reported (23). Angle decomposition sequencing for the pelvis and torso, and definitions of the movements they described are shown in Table 1. Throwing kinematics for left-handed subjects were calculated using the same conventions; however, it was necessary to mirror the world Z-axis so that all movements could be calculated, analyzed, and described from a right-hand point of view (34).

Once all initial setup and pretesting had been completed, subjects were allotted an unlimited time to warm-up. Subjects were allowed to perform their own specified precompetition warm-up routine but were asked to spend the latter portion of that warm-up time throwing from the indoor pitching mound to be used during the test trials. After completing their warm-up and gaining familiarity with the pitching surface, each participant threw a series of maximal effort fastballs for strikes toward a catcher located the regulation distance from the pitching mound (18.44 m). For the current study, those data from the fastest pitch passing through the strike zone were selected for detailed analysis (15,27).
Statistical Analyses

Data analysis for the current study was conducted using the statistical analysis package SPSS 11.5 for Windows (SPSS, Chicago, IL). For the fastest strike thrown by each participant, mean and SD for all sEMG and kinematic parameters were calculated. Once these measures of central tendency were calculated, a series of descriptive statistics were conducted to identify the presence of outliers and to determine the nature of each of the distributions in terms of both skewness and kurtosis. Once the data were deemed to be normally distributed through the calculation of Shapiro–Wilk statistic ($W$-statistic, $p > 0.05$), Pearson product moment correlation coefficients were then calculated to identify the possible relationships between gluteal activity and throwing kinematics. For the current study, although the data were derived from the same group of subjects at multiple intervals, the level of significance was retained at $p \leq 0.05$ as each phase of the pitching motion was analyzed as an independent interval. With regard to the observation of correlation power for the current study, significance was indicated by an observed power $\geq 0.80$.

### RESULTS

**Gluteal Activation**

The mean magnitudes of preferred gluteus maximus activity throughout the movement analysis are shown in Figure 2. For all pitchers, preferred gluteus maximus activity was observed to be in excess of 100% of their MVIC throughout the stride and arm-cocking phases of the pitching motion. From the end of the cocking phase (maximum external shoulder rotation) through the remainder of the movement, mean preferred gluteus maximus activity decreased to levels less than 100% of mean MVIC levels.

The observed means for the preferred gluteus medius (Figure 3), nonpreferred gluteus maximum (Figure 4), and nonpreferred gluteus medius (Figure 5), although different in magnitude, were similar in pattern. From the conclusion of the stride phase, through the conclusion of the arm-cocking phase, muscle activity increased for all pitchers. From this point, through the remainder of the pitching motion, muscle activity decreased to levels that remained fairly constant.

### Table 2. Mean (± SDs) for pelvis and torso kinematics at selected instances throughout the pitching motion.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Foot contact</th>
<th>Maximum external rotation</th>
<th>Ball release</th>
<th>Maximum internal rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvis lateral flexion (o)</td>
<td>−5 (±17)</td>
<td>−12 (±14)</td>
<td>−6 (±17)</td>
<td>−5 (±11)</td>
</tr>
<tr>
<td>Pelvis axial rotation velocity (o−1)</td>
<td>367 (±146)</td>
<td>678 (±148)</td>
<td>1019 (±449)</td>
<td>206 (±148)</td>
</tr>
<tr>
<td>Torso flexion (o)</td>
<td>16 (±17)</td>
<td>−7 (±8)</td>
<td>−18 (±8)</td>
<td>−27 (±14)</td>
</tr>
<tr>
<td>Torso lateral flexion (o)</td>
<td>−6 (±12)</td>
<td>−15 (±11)</td>
<td>−24 (±7)</td>
<td>−30 (±8)</td>
</tr>
<tr>
<td>Torso axial rotation velocity (o−1)</td>
<td>432 (±155)</td>
<td>705 (±190)</td>
<td>1277 (±548)</td>
<td>237 (±144)</td>
</tr>
</tbody>
</table>

### Table 3. Calculated Pearson product moment correlation coefficients ($r$) between preferred gluteal activity and both pelvis and trunk kinematics.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Preferred gluteus maximus activity</th>
<th>Preferred gluteus medius activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FC</td>
<td>MER</td>
</tr>
<tr>
<td>Pelvis lateral tilt (o)</td>
<td>0.346</td>
<td>0.285</td>
</tr>
<tr>
<td>Pelvis axial rotation (o−1)</td>
<td>0.106</td>
<td>0.730†</td>
</tr>
<tr>
<td>Torso flexion (o)</td>
<td>−0.118</td>
<td>−0.470</td>
</tr>
<tr>
<td>Torso lateral tilt (o)</td>
<td>−0.035</td>
<td>−0.586</td>
</tr>
<tr>
<td>Torso axial rotation (o−1)</td>
<td>0.048</td>
<td>0.439</td>
</tr>
</tbody>
</table>

*FC = foot contact; MER = maximum external rotation; MIR = maximum internal rotation; REL = ball release.
†Significant difference at $p \leq 0.05$.  

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Pelvis and Trunk Kinematics

Results of pelvis and trunk kinematics are given in Table 2. Throughout pitching motion, both the pelvis and the torso remained tilted laterally toward the glove hand with a slightly higher angle of lateral tilt being observed for the torso. Also, throughout the movement, both the pelvis and the torso rotated forward toward the plate with the velocity of axial torso rotation slightly exceeding the velocity of axial pelvis rotation. In addition, both peak axial rotation velocity and minimum axial rotation velocity for the pelvis preceded that of the torso.

Correlation

Correlation coefficients were computed to see if a possible relationship between gluteal activities throughout the phases of the pitching motion were related to pelvis and trunk kinematics at specific instances during the pitching motion. Pearson product moment correlation coefficients are shown in Table 3 (preferred gluteal activity/pelvis and trunk kinematics), Table 4 (nonpreferred gluteal activity/pelvis and torso kinematics), and Table 5 (dependent variable Interclass Correlation Coefficients).

Discussion

Typically the gluteus maximus acts to extend the hip and then allows for external rotation of the hip. The greater activation of the gluteus maximus on the preferred or drive leg indicated that it was active in externally rotating the drive hip throughout the arm-cocking and acceleration phases. From a kinematic chain standpoint, this increased activation may result in an increased rate of axial pelvis rotation throughout these phases. This is evident in the positive relationship ($r = 0.730, p \leq 0.05$ at maximum external rotation; $r = 0.831, p \leq 0.05$ at release) between the rate of axial pelvis rotation and preferred gluteus maximus activity at the points of maximum external shoulder rotation and ball release.

In a similar fashion, the gluteus medius acts as an internal rotator of the hips. As the nonpreferred leg (plant leg) was planted, the magnitude of gluteus medius activity increased. After foot contact, nonpreferred gluteus medius activity increased to a level near 145% of MVIC. This, coupled with the fact that the rate of axial pelvis rotation peaked just before release indicates that the nonpreferred gluteus medius may not simply function as a pelvic stabilizer throughout these phases, but may also function to allow for increased internal hip rotation during the arm-cocking and acceleration phases of the pitching motion.

### Table 4. Calculated Pearson product moment correlation coefficients ($r$) between nonpreferred gluteal activity and both pelvis and torso kinematics.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Nonpreferred gluteus maximus activity</th>
<th>Nonpreferred gluteus medius activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FC MER REL MIR</td>
<td>FC MER REL MIR</td>
</tr>
<tr>
<td>Pelvis lateral tilt (o)</td>
<td>-0.178 -0.171 -0.197 -0.126</td>
<td>0.011 0.107 0.048 0.015</td>
</tr>
<tr>
<td>Pelvis axial rotation (o/s)</td>
<td>-0.047 -0.550 0.837† -0.283</td>
<td>0.437 0.794† 0.779† 0.249</td>
</tr>
<tr>
<td>Torso flexion (o)</td>
<td>0.034 0.058 0.440 0.193</td>
<td>-0.034 -0.064 -0.051 -0.081</td>
</tr>
<tr>
<td>Torso lateral tilt (o)</td>
<td>-0.319 -0.248 -0.291 -0.046</td>
<td>-0.288 -0.088 -0.127 -0.156</td>
</tr>
<tr>
<td>Torso axial rotation (o/s)</td>
<td>-0.086 -0.164 -0.444 -0.133</td>
<td>0.318 0.346 0.634 0.227</td>
</tr>
</tbody>
</table>

*FC = foot contact; MER = maximum external rotation; MIR = maximum internal rotation.
†Significant difference at $p \leq 0.05$.

### Table 5. Calculated Interclass correlation coefficients (Pearson) between pelvis kinematics and torso kinematics.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pelvis lateral tilt (o)</th>
<th>Pelvis axial rotation (o/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FC MER REL MIR</td>
<td>FC MER REL MIR</td>
</tr>
<tr>
<td>Torso lateral tilt (o)</td>
<td>0.803† 0.759† 0.717 0.566</td>
<td>0.132 0.189 0.086 0.109</td>
</tr>
<tr>
<td>Torso axial rotation (o/s)</td>
<td>0.153 0.211 0.121 0.075</td>
<td>0.857† 0.917† 0.953† 0.956†</td>
</tr>
</tbody>
</table>

*FC = foot contact; MER = maximum external rotation; MIR = maximum internal rotation.
†Significant difference at $p \leq 0.05$. 

Pelvis and Trunk Kinematics

Results of pelvis and trunk kinematics are given in Table 2. Throughout pitching motion, both the pelvis and the torso remained tilted laterally toward the glove hand with a slightly higher angle of lateral tilt being observed for the torso. Also, throughout the movement, both the pelvis and the torso rotated forward toward the plate with the velocity of axial torso rotation slightly exceeding the velocity of axial pelvis rotation. In addition, both peak axial rotation velocity and minimum axial rotation velocity for the pelvis preceded that of the torso.
This is supported further by the observed positive relationship between axial pelvis rotation and nonpreferred gluteus medius activity (r = 0.794, p ≤ 0.05 at maximum external rotation; r = 0.779, p ≤ 0.05 at release). Also throughout the arm-cocking phase, preferred gluteus medius activity was observed to be inversely related to the rate of axial pelvis rotation (r = −0.824, p ≤ 0.05 at maximum external rotation). This again indicates that the role of the gluteus medius may be twofold, with it serving as both a pelvic stabilizer and an internal hip rotator with the latter action possibly being directly related to the ability of a pitcher to control the rate of axial pelvis rotation.

In examining the rate of axial torso rotation, no significant relationships were observed between any gluteal activity parameters and the rate of axial torso rotation. However, because the pitching motion progresses sequentially from the pelvis to the torso (1), variability in pelvic rotation may be directly related to variability in torso rotation. The interclass correlation coefficients calculated between the 2 dependent variables support this notion and indicate that the rate of axial torso rotation may be directly related to the rate of axial pelvis rotation.

**Practical Applications**

The findings from this study indicate that during the baseball pitch, there is a need for greater control of gluteal activation throughout the pitching motion. These findings may have implications for future injury prevention mechanisms within the pitching cycle. Furthermore, it can be inferred that the activation of the gluteal group may have a greater influence on the entire pitch vs. only trunk and pelvic control.

It has been previously suggested that throughout the pitching motion, kinematic alterations in the actions of proximal segments may result in kinematic alteration in the actions of distal segments (1,27) as in the actions of the pelvis could alter the actions of the torso. It has also been suggested that baseball pitchers who exhibit difficulty in controlling the rate of trunk rotation may increase their risks for injury (1). The results of the current study indicate that the pattern of gluteal activity observed throughout the pitching motion is directly related to the rate of axial pelvis rotation, and indirectly related to the rate of axial torso rotation. Thus, to better control the rate of both axial pelvis and torso rotation, high-school pitchers should focus on specific training techniques that will allow for the use of both the preferred and nonpreferred gluteal musculature in an appropriate manner throughout the pitching motion. By doing so, pitchers of this age may be able to better control both the rate and timing of axial rotation during pitching, and possibly decrease the risks of developing overuse injuries, such as to the elbow and shoulder that are commonly associated with poorly controlled trunk kinematics throughout the pitching motion. In an attempt to train the gluteal muscle group, athletes should focus on adequately training their core musculature through isometric exercises that address not only the abdominals but also the gluteal muscle group. Protocols such as the ones developed by Szymanski and Fredrick (28), Hendrick (13), Akuthota and Nadler (2), and Handzel (12) are great adjuncts to baseball training regimens.

**Acknowledgments**

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**References**


Glut Muscle Activity Relationship With Torso and Pelvis


