Kinematic analysis of the equestrian –
Walk, posting trot and sitting trot

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Abstract


The purpose of this study was to determine if significant differences existed between skill levels of riders at selected gaits. A high-speed video system analyzed the relative angles of the shoulder, hip and knee and the absolute angles of the upper arm, trunk, thigh and lower leg of 63 subjects at three levels of expertise; beginning, intermediate and advanced. Subjects performed at three gaits; walk, posting trot and sitting trot. Significant differences were found between the levels of riders for all angles, except the knee (p < 0.05). Significant differences were also found between all gaits for all angles, except the shoulder (p < 0.05). Descriptive statistics determined that the advanced rider positioned the upper body closest to the vertical and carried the upper arm furthest from the trunk.

1. Introduction

Some sports are more advanced than others in their application of technology to improve performance, and research on equestrian kinematics and kinetics is extremely limited. Leach and Crawford (1983) discussed the fact that further studies on the equestrian are necessary to determine the influence of the rider on the balance of the horse. Most previous studies have discussed the influence of the rider only as a secondary consideration to equine locomotion (Krüger, 1941; Deuel,

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1985; Dusek et al., 1970), have utilized data from low-speed film (ReQua, 1939; White, 1940) or have chosen small sample sizes of less than five subjects (ReQua, 1939; White, 1940; Cain, 1973; Fister, 1981). A solid foundation of scientifically validated information will offer the equestrian another tool to clarify current empirical knowledge, and therefore better understand the factors important to quality performance.

The purpose of this study was to determine if significant differences existed between skill levels of riders at selected gaits. If significant differences were found between skill levels of riders, then future studies could focus on an attempt to identify what kinematic variables were important in defining the ideal equestrian position. Several kinematic variables considered to be potentially useful to differentiate beginning, intermediate and advanced level equestrians at the walk, posting trot and sitting trot were compared. The relative angles of the shoulder, knee and hip and the absolute angles of the upper arm, trunk, thigh and lower leg of the different levels of riders were statistically analyzed.

The null hypothesis in this study was that no significant difference existed for the selected dependent variables between the levels of riders at the selected gaits. The alternative hypothesis was that a significant difference existed for the selected dependent variables between at least one of the levels of riders at the selected gaits.

2. Methodology

2.1. Subjects

Seventy-eight riders were video taped during five separate taping sessions. From this pool of 78 riders, 21 riders were selected at each level of expertise; beginning, intermediate and advanced, to yield a total subject pool of 63 (53 females and 10 males).

Three licensed dressage judges independently evaluated the skill level of each rider based on videos obtained during the data collection sessions. At least two of the three judges had to concur on the skill level of the rider or the subject was not used in the study. Eighty-one percent (17 out of 21) of the beginning level subjects, 67% (14 out of 21) of the intermediate and 95% (20 out of 21) of the advanced level
subjects were designated by all three judges as beginning, intermediate or advanced level riders respectively.

The subjects were chosen from a population of male and female riders located in the Midwest area of the United States. Subject selection was based on the subjective level of expertise of the riders, determined by the principle investigator, and availability of the subjects to participate in the study. The mean age of the subjects was 26 years with a range from 17 to 58 years, the mean body mass was 65 kg with a range from 41 to 104 kg and the mean height of the subjects was 168 cm with a range from 147 to 196 cm. The primary seat emphasis of 61% of the subjects was the English style of riding (dressage, eventing, hunt seat and saddle seat), and 39% the Western style of riding (endurance, reining and western pleasure).

2.2. Analysis system

The high-speed video system manufactured by the Motion Analysis Corporation (Santa Rosa, CA), was used to obtain the sagittal plane kinematic data for the study. Data were collected with a NAC MOS-TV 200/60 (Japan) high-speed video camera operating at a rate of 200 Hz and recorded on 1/2" Scotch Brand Professional Video Cassettes (3M Corporation, St. Paul, MN). A Schneider-Kreuznach Variogon (Germany) f1.8, 12.5–75 mm zoom lens set at a focal length of 22 mm was used in the study. The markers were 3.5–5.0 cm (average 4.25 cm) in diameter and the overall horizontal field width was approximately 731.5 cm. The calculation of the target to field-width ratio for this study was approximately 1:172.

The camera was positioned 91.4 cm from the ground at a distance of 21.3 m. from the track followed by the horse and rider. A single Photonics Analysis, Ltd. (Markham, Ontario) flood light with four bulbs (300 V–400 W each) was positioned directly behind the high-speed video camera. The light from the lamp reflected off the markers placed on the horse and rider and was captured by the camera and recorded on video tape.

The video signal was processed through the VP310 motion analyzer (Motion Analysis Corporation) utilizing the ExpertVision software package (Motion Analysis Corporation). The raw path coordinate data were smoothed using a recursive fourth-order Butterworth, zero-phase shift digital filter. The optimal cut-off frequency for each path was
determined after an examination of the second derivative of the Root Mean Square residuals (Jackson, 1979). A tolerance level of 0.05 was selected after a visual inspection of data smoothed with different tolerance levels. The computed optimal cut-off frequencies ranged from 1.5 to 9.5 Hz. The smoothed paths were then used to calculate the angle data for each trial.

2.3. Marking of subjects and horse

Four reflective spheres (3.5 cm) were used on the riders as joint markers according to anatomical landmarks established by Plagenhoef (1971) and Clauser et al. (1969). These markers were placed on the left side of each subject on the lateral malleolus (ankle), the lateral side of the center of the flat portion of the condyles of the femur (knee), the lateral bony prominence of the greater trochanter (hip) and the glenohumeral joint center (shoulder). One additional reflective sphere was positioned on the rider’s upper arm to serve as a reference point for determination of the shoulder angle.

A reflective disk (5 cm) was placed on the horse’s metacarpophalangeal joint (fetlock) at the midpoint of the lateral condyle of the third metacarpal bone. The fetlock marker served as a reference point to determine the position of the horse’s leg during the stride se-

![Fig. 1. Relative and absolute angles.](image-url)
quence. Fig. 1 illustrates the relative and absolute angles analyzed in this study.

2.4. Procedures

The video taping was performed in an indoor riding arena (24 m × 61 m) containing sand footing. All riders rode the same horse, an aged Thoroughbred mare, 16.1 hands tall, and used a Crosby Mark IV all-purpose saddle and snaffle bridle. None of the subjects had previous experience riding this horse. The mare exhibited long, bouncy strides at the walk and trot which would challenge the correct riding position of the subjects. However, the horse was well trained and was easily controlled by all levels of riders.

Each horse and rider followed the same perpendicular path down the long wall of the arena. The riders were limited to a ‘warm-up’ period of up to five minutes. All subjects were video taped at the walk, posting trot and sitting trot and the order of the gaits each rider performed was randomly selected.

Constant contact of the rider with the saddle while the horse is trotting is defined as the sitting trot. The sitting trot is typically seen during a slow trot in Western riding. Riders also sit to the faster, longer strided trot when more contact and control over the movement of the horse is desired by the rider (Evans, 1981; Morris, 1979). However, to make the faster, longer strided trot more comfortable the rider will sometimes rise out of and sit into the saddle with the two-beat rhythm of the trot. This action is referred to as posting to the trot. Generally, the rider should post with the outside front, inside hind diagonal pair of the horse’s legs when performing turns and while on straight lines (Morris, 1979).

Riders were video taped twice at each gait for a minimum of two strides and the clearest trial was selected for use in the study. All markers had to be visible at the beginning and end of the two strides for the trial to be determined clear. If both trials were clear, the first trial was chosen for analysis.

The mid-stance instant of the left forelimb of the horse was chosen as one of the discrete points for analysis because it was an easily defined point to determine the beginning and end of each stride sequence. The mid-stance instant was the discrete point in time when the centroid of the fetlock joint marker was at its lowest point relative
to the ground (Drevemo et al., 1980). During the mid-stance instant, the riders in this study were at the mid point of their rise to the posting trot.

The second point chosen for statistical analysis was the mid-swing instant of the left forelimb of the horse. The mid-swing instant was calculated as 50% of the time between the two mid-stance instances at the beginning and end of each stride. During the mid-swing instant of the posting trot, the riders in this study would be in mid contact with the saddle.

The relative and absolute joint angles of the rider were calculated at the mid-stance and mid-swing instances of the stride. For the two strides taped, the data points at the three mid-stance instances were averaged and the data points at the two mid-swing instances were averaged. One mid-stance value and one mid-swing value for each dependent variable were then used in separate statistical analyses.

2.5. Statistical analysis of data

The statistical analyses in this study were performed using the SAS statistical package produced by SAS Institute Incorporated (Cary, North Carolina). A one between, one within repeated measures analysis of variance (ANOVA) was performed on the dependent variables calculated for the beginning, intermediate and advanced level riders (ability) at the walk, posting trot and sitting trot (gait). In addition, descriptive statistics were used to provide a general understanding of the selected dependent variables.

If a significant main effect occurred and there was no interaction, Tukey's follow-up tests (Howell, 1987) were used to determine which means varied. If an interaction occurred, interaction graphs were drawn to clarify the interaction results. If the interaction graphs determined that follow-up tests were justified, pairwise follow-up tests using Bonferroni's procedure (Howell, 1987) were performed. In all statistical tests, the 0.05 level of significance was used. For the shoulder angle during mid stance on ability, a p-value of 0.0513 was calculated. Arguments can be made both for significance and for nonsignificance when the p-value is so close to the chosen level of significance. In the following discussion, the authors determined that the p-value for the shoulder angle during mid stance was significant.
3. Results

The results of the repeated measures ANOVA are listed in Table 1. Where an interaction occurred, interaction graphs were drawn and the results are illustrated in Fig. 2.
Table 1
Inferential statistics of relative and absolute angles

<table>
<thead>
<tr>
<th>Variable</th>
<th>Stride phase</th>
<th>Ability ANOVA&lt;sup&gt;a&lt;/sup&gt; (p-value)</th>
<th>Tukey's&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Gait ANOVA&lt;sup&gt;a&lt;/sup&gt; (p-value)</th>
<th>Tukey's&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Ability × gait ANOVA&lt;sup&gt;a&lt;/sup&gt; (p-value)</th>
<th>Bonferroni&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Walk</th>
<th>Post trot</th>
<th>Sit trot</th>
</tr>
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<tbody>
<tr>
<td>Hip</td>
<td>Mid stance</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>beg-adv</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>w-st</td>
<td>0.3523</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mid swing</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>beg-inter</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>st-pt</td>
<td>0.3287</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee</td>
<td>Mid stance</td>
<td>0.5320</td>
<td>beg-adv</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>all</td>
<td>0.3933</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mid swing</td>
<td>0.9376</td>
<td>beg-adv</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>all</td>
<td>0.7927</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder</td>
<td>Mid stance</td>
<td>0.0513&lt;sup&gt;f&lt;/sup&gt;</td>
<td>beg-inter</td>
<td>0.5276</td>
<td>w-pl</td>
<td>0.3290</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>Mid swing</td>
<td>0.0070&lt;sup&gt;f&lt;/sup&gt;</td>
<td>beg-inter</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>st-pt</td>
<td>0.0764</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Trunk</td>
<td>Mid stance</td>
<td>0.0002&lt;sup&gt;f&lt;/sup&gt;</td>
<td>beg-adv</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>beg-adv</td>
<td>0.0009&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
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<tr>
<td></td>
<td>Mid swing</td>
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<td>beg-adv</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>beg-adv</td>
<td>0.0009&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
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<tr>
<td>Thigh</td>
<td>Mid stance</td>
<td>0.0692</td>
<td>beg-adv</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>beg-adv</td>
<td>0.0022&lt;sup&gt;f&lt;/sup&gt;</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>Mid swing</td>
<td>0.1839</td>
<td>beg-adv</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>beg-adv</td>
<td>0.0012&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower leg</td>
<td>Mid stance</td>
<td>0.0251&lt;sup&gt;c&lt;/sup&gt;</td>
<td>beg-adv</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>all</td>
<td>0.3671</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Mid swing</td>
<td>0.2563</td>
<td>beg-adv</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>all</td>
<td>0.4213</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Upper arm</td>
<td>Mid stance</td>
<td>0.0002&lt;sup&gt;f&lt;/sup&gt;</td>
<td>beg-adv</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>beg-adv</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mid swing</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>beg-inter</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td>beg-inter</td>
<td>0.0001&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
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</table>

<sup>a</sup> n = 63.
<sup>b</sup> df = 60, α = 0.05; <sup>c</sup> df = 120, α = 0.05.
<sup>d</sup> p < 0.05; <sup>e</sup> p < 0.05; <sup>f</sup> p < 0.01; <sup>g</sup> marginal level of significance at p < 0.05 (see text).
Fig. 3. Descriptive statistics – Walk (average of mid-stance and mid-swing phases).

For a descriptive interpretation of the results of this study, the mean values of the relative angles were calculated for the different levels of riders (Figs. 3–6). The popular literature does not discuss differences in correct riding position during the mid-stance and mid-swing phases of the stride during the walk and sitting trot (Wright and
Kelley, 1975; Littauer, 1976; Museler, 1978; Morris, 1979; Morris, 1981; Swift, 1985). Therefore, the mid-stance and mid-swing angle values for these two gaits were averaged to obtain the illustrated mean angle values in Figs. 3 and 4.
4. Discussion

4.1. Ability

On ability, significant main effects and interactions were found on the dependent variables for mid stance and mid swing (Table 1). Only the relative angle of the lower leg did not show the same significant differences for mid stance and mid swing. This implies that except for the knee angle, both the mid-stance and mid-swing phases of the stride may be useful in determining the significance of selected variables.

Only the relative angle of the knee showed no significant main effect on ability and no interaction occurred. This may indicate that the knee angle is not important in differentiating between the ability levels of riders. Interactions occurred for the absolute angles of the trunk, thigh and upper arm. As a result, interpretation of these data becomes more complicated.

4.2. Gait

On gait, with one exception, the dependent variables were significant during both the mid-stance and mid-swing instances of the stride. Only the relative angle of the shoulder showed a significant difference during mid swing, but not during mid stance. Therefore, to determine if a significant difference occurred on gait for the selected dependent variables either the mid-stance or mid-swing points would probably be suitable, except for the shoulder angle.

4.3. Dependent variables without interactions

Hip

For the relative angle of the hip, a significant difference was found between ability and between gait for both the mid-stance and mid-swing instances of the gaits. In addition, no interactions occurred. Therefore, based on the results of this study the relative hip angle of the rider may be useful in differentiating between ability and between gait.

Tukey’s follow-up tests on the relative angle of the hip on ability determined a significant difference between the beginning and ad-
vanced level riders, which would be expected (Table 1). During mid swing, a significant difference was also found between the beginning and intermediate level riders, suggesting that a greater degree of change occurred as the rider moved from the beginning to intermediate level, than from the intermediate to advanced level.

The follow-up tests on gait for the relative angle of the hip during mid swing found a significant difference between all three gaits, which would be expected. However, during mid stance significant differences were found between the walk and sitting trot, and posting and sitting trot. The significant difference between the walk and sitting trot was interesting because a similar hip angle at the walk and sitting trot had been advocated in the popular literature (Morris, 1979; Swift, 1985; Wright and Kelley, 1975). However, based on the results of this study a significant difference was found for the hip angle during the walk and sitting trot.

During mid stance, no difference was found for the hip angle between the walk and posting trot. This similarity was surprising because during the mid-stance instant the rider in this study was in the rise phase of the posting trot. No subjective comparisons between the hip angles of the riders at the walk and the rise phase of the posting trot has been made in the literature. Comparisons such as this, between the angles of the riders at the different gaits, could be useful in explaining the correct position to the rider. For example, an explanation to the rider of the proper angle of the hip at the rise to the posting trot could be associated with the hip angle the rider should maintain during the walk.

Knee

The relative angle of the knee was the only dependent variable that did not have a significant difference on ability, indicating that it may not be useful in differentiating between levels of riders. However, the related absolute angles of the thigh and lower leg showed significant differences. Therefore, it appears that to more clearly understand the significance or nonsignificance of a relative angle, the associated absolute angles must also be considered.

On gait, Tukey's follow-up tests showed significant differences between all three gaits for both mid stance and mid swing. Therefore, differences existed in the knee angle between the walk, posting trot and sitting trot which would be expected.
Lower leg

A significant difference was found for the lower leg angle on ability only during mid stance. This may indicate that if the angle of the lower leg is used to differentiate between levels of riders the calculations should be taken during the mid-stance instant of the. Tukey’s follow-up tests on ability for the lower leg during mid stance found a significant difference between beginning and advanced level riders, which would be expected.

The absolute angle of the lower leg of the rider was significantly different for gait during both mid stance and mid swing. The follow-up tests determined that significant differences existed between all three gaits. Therefore, the lower leg angle may be a good variable to differentiate between the three gaits selected in this study.

Shoulder

The relative angle of the shoulder was found to be significantly different on ability during mid stance and mid swing. Tukey’s follow-up tests for the relative angle of the shoulder found a significant difference only between the beginning and intermediate level riders. No significant difference in the shoulder angle between the intermediate and advanced level riders was observed which would not be unusual. However, an unexpected similarity was found between the beginning and advanced level riders. The later discussion of the absolute angles of the trunk and upper arm will attempt to clarify the similarities and differences observed between the levels of riders in the shoulder angle.

A significant difference was found on gait during mid swing but not during mid stance. Therefore, it may be important to determine the stride phase of the gait when analyzing equestrian position between the different gaits. For the relative angle of the shoulder on gait during mid swing, a difference was observed between the walk and posting trot, and posting trot and sitting trot, but not between the walk and sitting trot. The walk is a relatively slow, steady gait therefore minimal movement in the rider’s shoulder angle would be expected. However, the sitting trot is a much more vigorous gait and more movement in the rider’s shoulders would be expected when compared to the walk. A subjective observation showed that during the sitting trot the movement of the rider occurred mainly in the rider’s back and lower body. The shoulder angle of the rider did not
change much, especially in the advanced level rider. Therefore, the lack of a significant difference for the shoulder angle between the walk and the sitting trot was understandable.

4.4. Dependent variables with interactions

Interactions between ability and gait occurred for the trunk, upper arm and thigh angles. An overall assessment of the interaction graphs of these dependent variables determined that a disordinal pattern existed (Fig. 2), therefore Bonferroni’s follow-up tests were justified. However, the possibility of rejecting the null hypothesis when it is true is increased as the number of pairwise comparisons are increased. Therefore, the results of pairwise comparisons must be viewed critically.

Trunk

Pairwise follow-up tests on the trunk angle found significant differences between the beginning and advanced level riders at the posting trot during mid stance and mid swing. Differences between the two levels of riders would be expected, so these results were not surprising. In addition, the lack of a significant difference between the beginning and intermediate and intermediate and advanced level riders may indicate that the change in the rider’s position occurred gradually.

For the sitting trot during mid stance and mid swing, a significant difference was found for the trunk angle between the beginning and advanced level riders, and between the intermediate and advanced level riders. The significant difference between the intermediate and advanced level riders may indicate that the absolute trunk angle was a useful variable to differentiate between these levels of riders during the sitting trot. Only one other dependent variable, the upper arm angle at the sitting trot during mid stance, showed a significant difference between the intermediate and advanced level riders. It would be assumed that fewer differences would occur between the intermediate and advanced level riders, and the data from this study substantiated this assumption. Therefore, these two variables may be important when attempting to differentiate between intermediate and advanced level riders.
No significant differences in the trunk angle existed between the levels of riders at the walk during mid stance and mid swing. Since the walk is a slower, steadier gait when compared to the posting and sitting trots this similarity was not surprising.

**Thigh**

During the sitting trot, no significant differences were found for the thigh angle between the levels of riders. Therefore, the significant difference in the hip angle on ability at the sitting trot could be assumed to be dependent upon the significant difference in the related trunk angle rather than in the thigh angle.

In the walk and posting trot, significant differences were found for the thigh angle during mid stance for the beginning and advanced level riders. At the walk during mid swing, a significant difference was also found between the beginning and advanced level riders. As stated previously, differences between the beginning and advanced level riders would be expected. It should be noted that no significant differences were found for the posting trot during mid swing for the absolute angle of the thigh. Therefore, this again may indicate the importance of analyzing both the mid-stance and mid-swing phases of the stride for certain dependent variables.

The related angle of the trunk showed a significant difference for the posting trot during mid swing and mid stance between the beginning and advanced level riders. The thigh angle also showed a significant difference during mid stance between the beginning and advanced level riders. Therefore, at the posting trot during mid stance the significant difference in the hip was perhaps due to both of the related thigh and trunk angles. However, at the walk no significant difference existed for the trunk angle. Therefore, the significant difference observed in the hip between the beginning and advanced level riders at the walk was probably due to the change in the thigh angle.

The relationship between the angles of the thigh and lower leg and the relative angle of the knee was not clear. Although the knee angle on ability was not significant, the thigh and lower leg angles were significant on ability in certain cases. Perhaps the positions of the thigh and lower leg relative to the horizontal were more important than the resultant angle of the knee in differentiating between ability levels.
Upper arm

Pairwise follow-up tests on the upper arm angle found a significant difference at the walk between the beginning and advanced level riders during mid stance but not during mid swing. At the posting and sitting trots, significant differences were found for both the beginning and intermediate riders, and the beginning and advanced riders during mid stance and mid swing. In addition, at the sitting trot during mid stance a significant difference was found between the intermediate and advanced level riders. This was the only variable in the pairwise tests that displayed a significant difference between all three levels of riders at a particular gait.

The shoulder angle is the resultant angle of the upper arm and trunk body segments. Tukey’s follow-up tests for the relative angle of the shoulder on ability showed a significant difference only between the beginning and intermediate level riders. The pairwise follow-up tests on the trunk showed no significant differences between the beginning and intermediate level riders for any of the three gaits. However, the pairwise tests on the upper arm angle showed a significant difference between the beginning and intermediate level riders during the posting and sitting trots. Therefore, the significant difference in the relative shoulder angle between the beginning and intermediate level riders may be due to a significant difference in the upper arm angle rather than in the trunk angle during the posting and sitting trots.

The lack of a significant difference in the shoulder angle between the beginning and advanced level riders was more difficult to interpret. Pairwise follow-up tests found significant differences for the trunk and upper arm angles for the beginning and advanced riders at the posting and sitting trots during mid stance and mid swing. In the walk, the upper arm angle showed a significant difference between the beginning and advanced riders only during mid stance. It is possible that a significant difference in two absolute angles could result in the lack of a significant difference in the resultant relative angle.

4.5. Summary

Gait

Of all the dependent variables selected for this study only the relative angle of the shoulder during mid stance did not show a
significant difference on gait. The gaits were selected based on the assumption that they would vary and therefore the results obtained in this study were expected.

**Ability**

The different levels of riders were expected to be significantly different for the selected dependent variables and overall the results confirmed these differences. However, the results offered some insight into exactly where the differences existed between the levels of riders.

The relative angle of the hip was significantly different on ability. However, for the related absolute angles of the trunk and thigh significant interactions made the interpretation of the results more complicated. During the walk, the thigh angle was significant, therefore it may be more influential than the trunk angle in determining the significant difference of the hip. For the posting trot, both the trunk and thigh angles were significant and may both be influential in determining the difference observed in the hip angle. However, during the sitting trot only the trunk angle was significant and therefore may be more important when determining the cause of the significance of the hip angle. Based on the descriptive statistics, the advanced level rider maintained the most obtuse hip and trunk angle of the three levels of riders.

The knee angle appeared to have no influence on the position of the rider since no significant difference was found on ability. However, both the related angles of the thigh and lower leg showed some significant differences. Therefore, to understand the importance of the significant and nonsignificant angles the relative angle and the related absolute angles must be considered. Based on the descriptive statistics, the advanced rider carried the lower leg further under the body. However, since significant differences were determined in both the thigh and lower leg with no associated significant difference in the knee, it was difficult to determine if this position of the lower body was due to a more vertical position of the thigh or a more posterior position of the lower leg, or both.

The shoulder angle showed a significant difference in ability. Overall, the trunk and upper arm angles were significantly different, therefore the difference in the shoulder angle was probably due to both of these related absolute angles. Based on the descriptive statis-
tics, the beginning level rider carried the upper arm closer to the vertical and closer to the body than did the other two levels of riders.

5. Conclusions

Many physical, environmental and mental elements must be considered when attempting to differentiate between performance levels of equestrians. However, the popular literature contains very few quantitative explanations of the desired position of the rider. The kinematic description offered in this study is a starting point for understanding the diverse components necessary to obtain quality performances by equestrians. The most desirable position of the equestrian is not dependent only upon the kinematic variables discussed in this study.

An observation of the descriptive statistics showed that the advanced level rider sat closer to the vertical in all gaits, positioned the thigh and lower leg under their body, and carried the upper arm ahead of the trunk. These findings approximate the ideal position of the equestrian described in the popular literature.

The inferential statistics in this study found significant differences between the levels of riders for selected dependent variables. The performance of the horse may be influenced by the ability of the rider, and therefore the ability level of the rider should be determined in equine locomotion studies where the horse is ridden.

The majority of significant differences on ability were found in this study between the beginning and advanced level riders. This would indicate a gradual change in the rider's position as the ability of the rider progressed. Only a few dependent variables showed a significant difference between beginning and intermediate and intermediate and advanced level riders.

It appeared that to more clearly understand the results of a relative angle, the absolute angles that comprise that relative angle must also be analyzed. For example, if significant differences were determined for two related absolute angles the associated relative angle was not necessarily significant. In addition, a significant relative angle did not necessarily mean that both of the related absolute angles were significant. It was also interesting to note that only the absolute angles showed significant interactions.
The same pattern of significant differences was not observed during the mid-stance and mid-swing instances of the stride. These significant differences are understandable during the posting trot due to the asymmetrical nature of the posting trot. However, the differences during the sitting trot and walk are not as easy to explain. Therefore, for certain dependent variables it may be important study both stride phases.

Today with the accessibility of data from the analysis of high-speed film and video the technology exists to help the equestrian analyze riding technique. Riding is a very complex sport. Skills, personalities and perceptions of both horse and rider must be combined to obtain a quality performance. With the use of quantitative analysis, the equestrian sports may be able to more clearly understand the elements necessary to consistently produce a performance of high quality.

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