Electromyographic analysis of the rider’s muscles at trot

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Abstract
The aim of this study was to investigate rider muscle activity in relation to horse movement. Electromyographic (EMG) activity of 12 upper-body muscles was recorded simultaneously with the horse’s footfall timing for six riders, riding the same horse at trot. Data for five strides were analysed for each rider. Rectus abdominis, upper trapezius, middle trapezius, flexor carpi radialis, biceps brachii, triceps brachii and middle deltoid muscles had constant patterns with two peaks occurring in the same phase of the stride in all riders. Peak EMG values in the upper trapezius and middle trapezius occurred in early stance, and were considered to stabilize the rider’s neck and scapula during impact of the diagonal limbs. The rectus abdominis showed peak EMG activity in mid-stance to stabilize the trunk and enable the rider to follow the horse’s movement by swinging the pelvis forward as the horse’s body reversed direction from downward to upward motion. The triceps brachii, which was active during late stance, and the biceps brachii, which was activated early in stance, stabilized the rider’s hands and maintained contact with the bit.

Teres major, extensor carpi ulnaris and serratus anterior muscles had a small range of activity (33, 26 and 37%, respectively), consistent with tonic activation or were inactive, suggesting that their function may be related to general postural control.

Keywords: equestrian sport; electromyography; EMG; horseback riding

Introduction
Equestrian sports involve two athletes, one equine and one human. The motion of the horse’s limbs and trunk varies according to the gait being performed. The rider should follow the motion of the horse’s body in a harmonious manner, which implies having the ability to adapt to the motion patterns that are characteristic of the different gaits. In the trot, each stride consists of two diagonal stance phases alternating with two flight phases. The horse’s trunk ascends from mid-stance until the middle of the flight phase, then descends during the second half of the flight phase and early stance. Thus, the direction of the horse’s body movement reverses in mid-stance and in mid-swing.

Co-ordinated contractions of the rider’s muscles are used to stabilize the rider’s position, to follow the motion of the horse’s body and to influence the horse’s performance. It would be expected that when muscles act to stabilize the rider or to follow the horse’s movement, their activity patterns would be co-ordinated with the rhythm of the stride, giving each gait a characteristic, cyclic pattern of muscle activation. Use of the rider’s muscles to influence the horse’s performance is likely to show a more variable pattern of muscle activation.

Electromyography (EMG) offers a simple technique for detecting muscle activation and co-ordination patterns. Its applications in equestrian sports have been limited, and have focused on function of the back muscles. For instance, it has been shown that, at the sitting trot, novice riders used their adductor magnus muscle to maintain their posture because of lack of co-ordination between the rectus abdominis and erector spinae. Insight into activation of the...
muscles of the arm and shoulder girdle may provide further insight into riding technique and the rider’s effects on equine performance. Hence the aim of this study was to analyse and compare the timing of EMG activity in muscles in the rider’s body with the temporal stride variables of the horse at trot.

Materials and methods

Subjects
Six experienced female riders participated in the study. The subjects’ height was 1.64 ± 0.04 m and mass was 61 ± 7 kg (mean ± standard deviation (SD)). Testing was performed in accordance with Michigan State University’s human and animal ethics committees and riders provided written informed consent. All riders rode the same horse, a 1.56-m, 508-kg, 16-year-old, Thoroughbred dressage horse. Riders were instructed to warm up in an arena, then trot along a 130-m rubberized runway at a consistent speed. Recordings were made as the horse and rider passed through the middle 30 m of the runway.

Procedure
EMG recordings were made from 12 muscles in two sets of six, on the right side of the rider’s body. The first set of six muscles consisted of the rectus abdominis, upper trapezius, middle trapezius, lower trapezius, serratus anterior and teres major. The second set of six muscles consisted of the flexor carpi radialis, extensor carpi ulnaris, biceps brachii (short head), triceps brachii (long head), middle deltoid and sternal head of the pectoralis major. These muscles are commonly cited as important in the control of the horse.

Two self-adhesive, disposable surface electrodes with a surface area of 1.5 cm² were positioned over each muscle, 2 cm apart. Single-differential signal detection was used, which at a 2 cm electrode separation introduces marginally more crosstalk than through use of double-differential (18% vs. 15%). A ground electrode was attached over the proximal head of the clavicle. For each set of muscles, EMG data were sampled at 1200 Hz from five trotting trials, with each trial being 5 s in duration. Data were transmitted using a telemetered system (Noraxon, Scottsdale, AZ) and recorded using Evart 3.2.1 software (Motion Analysis Corporation, Santa Rosa, CA). All trials were filmed at 60 Hz by a JVC GR-DVL9800 (Yokohama, Japan) camera, using the time code of the system to synchronize the ground contact timings of the hooves with the EMG data. The sampling frequencies are appropriate for the frequency of the signal in accordance with the sampling theorem (i.e. fast for EMG, slow for stride timings). Errors in synchronizing the signals using the Evart software are considered negligible.

Analysis
Data were analysed using custom-written code in MATLAB v13 (MathWorks Inc., Natick, MA). The EMG raw data were smoothed using a high-pass filter with a cut-off frequency of 10 Hz and full-wave rectified. EMG data from each trial were separated into 10 phases starting with toe-off of the left forelimb. The two flight phases in the stride (Flight 1 and Flight 2) were subdivided into early and late parts, and the two stance phases (Stance 1 and Stance 2) were subdivided into early, middle and late parts to provide the 10 phases for the entire stride. The video recordings were used to identify the timing of limb contacts and lift-offs from which the flight and stance phases were determined.

Within each trial, to cater for trials of different duration, the ‘mean activity for each phase’ was presented as a percentage of the ‘total activity for the trial’. To cater for different signal magnitudes between muscles, the ‘mean activity for a phase’ was presented as a percentage of the maximum ‘mean activity for a phase’ within a trial. These mean values were then averaged for the five trials by each subject to provide each subject’s mean values, which for the six subjects were used to calculate the group’s mean ± SD. Peak EMG values were determined for the first and second half of each trot stride. With the phases numbered from 1 to 10, the mean ± SD of the phase in which peak EMG values occurred for each muscle was determined for the six riders. In one subject, no data were available from the pectoralis major. The appropriateness of this normalization procedure is addressed at the beginning of the Discussion section.

Results

The horse’s stride duration of 0.8 ± 0.02 s consisted of two flight phases (0.2 ± 0.03 s) and two stance phases (0.6 ± 0.03 s). Raw EMG data for one rider (Fig. 1) and values averaged over all riders during each phase (Fig. 2) had a similar pattern in the first half (Flight 1 and Stance 1) and second half (Flight 2 and Stance 2) of the stride. The EMG signals indicate that the middle trapezius and lower trapezius were active during the flight phase until mid-stance; the upper trapezius was active in early stance; and the pectoralis major and rectus abdominis were active in the second half of stance (Fig. 1). For the muscles of the arm and forearm, the flexor carpi radialis, biceps brachii and middle deltoid were active in the early stance phase; and the triceps brachii was active in the late stance phase (Fig. 1). As Fig. 1 presents a single trial, some deviations from the average results presented in Fig. 2 and Table 1 are present.

Peak EMG values occurred in early stance in upper trapezius, middle trapezius, flexor carpi radialis, flexor carpi radialis,
biceps brachii and middle deltoid muscles; in the middle part of the stance phase in the rectus abdominis; and in late stance in the triceps brachii (Table 1). Most of the muscles had two distinct peaks in each stride. Variability in the timing of the EMG peak values, and the phase in which peak values occurred, indicate that the serratus anterior did not have a determinable pattern. Teres major, extensor carpi ulnaris and pectoralis major muscles were variable in their timing (e.g. SD for phase 1: 0.8 for teres major and pectoralis major, 1.2 for extensor carpi ulnaris), whereas middle deltoid and flexor carpi radialis muscles were consistent in their time of occurrence. The range between maximum and minimum EMG values (Table 1) was largest for the upper trapezius and smallest for the extensor carpi ulnaris. A small value suggests a more tonic muscular contraction in the extensor carpi ulnaris (26%), teres major (33%) and serratus anterior (37%). The other muscles had a larger range and their peak values occurred at similar times in each stride, which is typical of an activity pattern with discrete bursts of muscle activity.

**Discussion**

Muscle activity has been studied in a variety of sports. In many of these studies, data were analysed with respect to maximal voluntary contraction, but this
method of normalization is not particularly useful when muscular activity is used for control rather than for power generation.\textsuperscript{7,8} In equestrian sports, such as in horse riding, contractions of the rider's muscles are more important for stabilization and control of the rider's position and co-ordination of the rider's movement, rather than for production of power. Furthermore, the relatively static position of  

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{muscular_activity.png}
\caption{Muscular activity for 12 muscles of six subjects over 10 phases of the stride. Each datum point represents mean activity during a phase of the stride expressed as a percentage of maximal activity for that muscle. Dashed lines indicate one standard deviation. Vertical dotted lines separate the four consecutive phases of Flight 1, Stance 1, Flight 2 and Stance 2.}  
\end{figure}
the rider’s body segments during riding suggests that it is inappropriate to measure maximum voluntary contraction for the muscles being studied. Therefore, muscle activities were normalized to a percentage of the total activity for the trial, and not to maximal voluntary contraction. This provided an indication of the timing of muscle activity that could be related to ground contact times of the horse’s limbs, rather than providing an estimate of relative muscle contraction force.

In the initial part of stance, the horse’s limbs are rapidly decelerated, and the rider’s body must be stabilized to prevent collapse under the influence of impact forces. The horse’s body then descends until mid-stance, when the downward motion of the horse’s trunk reverses. Evaluation of ground reaction forces at trot showed that the rider has a dynamic effect on the horse’s weight distribution that is not equivalent to simply increasing the weight of the horse’s trunk reverses. The simplification of using hoof contact to infer joint. The simplification of using hoof contact to infer the phase in which they occur. Timing SD is expressed as the number of phases

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Peak 1 (%)</th>
<th>Peak 2 (%)</th>
<th>Range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectus abdominis</td>
<td>66 ± 8</td>
<td>77 ± 9</td>
<td>57</td>
</tr>
<tr>
<td>Upper trapezius</td>
<td>92 ± 8</td>
<td>71 ± 13</td>
<td>77</td>
</tr>
<tr>
<td>Middle trapezius</td>
<td>73 ± 20</td>
<td>84 ± 6</td>
<td>62</td>
</tr>
<tr>
<td>Lower trapezius</td>
<td>69 ± 21</td>
<td>76 ± 11</td>
<td>48</td>
</tr>
<tr>
<td>Serratus anterior</td>
<td>–</td>
<td>–</td>
<td>37</td>
</tr>
<tr>
<td>Teres major</td>
<td>68 ± 15</td>
<td>70 ± 7</td>
<td>33</td>
</tr>
<tr>
<td>Flexor carpi radialis</td>
<td>84 ± 14</td>
<td>70 ± 16</td>
<td>48</td>
</tr>
<tr>
<td>Extensor carpi ulnaris</td>
<td>69 ± 22</td>
<td>58 ± 12</td>
<td>26</td>
</tr>
<tr>
<td>Biceps brachii</td>
<td>83 ± 11</td>
<td>67 ± 13</td>
<td>62</td>
</tr>
<tr>
<td>Triceps brachii</td>
<td>53 ± 27</td>
<td>68 ± 20</td>
<td>41</td>
</tr>
<tr>
<td>Middle deltoid</td>
<td>70 ± 12</td>
<td>77 ± 8</td>
<td>59</td>
</tr>
<tr>
<td>Pectoralis major</td>
<td>71 ± 19</td>
<td>62 ± 16</td>
<td>44</td>
</tr>
</tbody>
</table>

The rectus abdominis was activated in mid-stance. Contraction of this muscle raises intra-abdominal pressure by increasing fascial tension, perhaps assisted by the oblique abdominal muscles, which are also utilized for increasing abdominal pressure. It has been found that an increase in intra-abdominal pressure is a mechanism for stabilizing the trunk by stiffening the spinal column. The timing of rectus abdominis activation may also allow the rider to follow the horse’s movement by swinging the pelvis forward as the horse’s body reverses direction in mid-stance and starts to rise. In future studies, analysis of the activation patterns of other abdominal and back muscles will clarify the importance of those muscles for stabilizing the rider’s posture and following the horse’s movement.

The biceps brachii and triceps brachii elicited maximum activity in different phases (Fig. 2; Table 1). The biceps brachii was active at the beginning of stance, whereas triceps brachii was active during late stance. The biceps brachii may control the elbow and stabilize the position of the forearm during the impact phase by counteracting its tendency to descend. The alternating activity in the elbow flexors and extensors could also be a mechanism for maintaining constant rein tension by keeping a consistent distance between the rider’s hand and the horse’s bit through opening and closing the angle of the elbow joint. The simplification of using hoof contact to infer
back motion as detailed in previous observations\textsuperscript{15} was beneficial, but synchronous collection of EMG data with kinematic data from the rider’s arm and the horse’s trunk, neck and head would provide more precise data to test this hypothesis, and to distinguish between tonic or concentric muscle activity.

Muscles that have a high SD for the timing of the peaks in muscle activity (phases 1 and 2: teres major 0.8 and 0.8, extensor carpi ulnaris 1.2 and 0.8, pectoralis major 0.8 and 0.5) do not have a consistent activity pattern between subjects and their activity may be related to controlling the movement of the horse, for example, by adjusting rein tension. When the range difference between maximum and minimum is small, it indicates that muscle activity is tonic or that the muscle is inactive (e.g. teres major 33\%, extensor carpi ulnaris 26\%, serratus anterior 37\% of maximum). These muscles may be used to maintain the position of the arm relative to the trunk (teres major and serratus anterior), or to maintain the position of the wrist (extensor carpi ulnaris).

The latissimus dorsi has a similar function to the teres major\textsuperscript{16} but can create more power and may play a greater role in the interaction between horse and rider. Since the latissimus dorsi is located in the lower part of the thorax, however, it may be activated passively by the horse’s body movement, and this is the reason why the teres major was preferred for evaluation in this study. This effect was apparent in the lower trapezius muscle, in which the phases of peak activity were different in the two halves of the stride, suggesting that activity for this muscle is dependent on whether the horse is in the left or right diagonal stance phase.

**Conclusion**

Activation patterns of most of the muscles were consistent between riders, showing activity at key times during the stride. At the beginning of the stance phase, the upper and middle trapezius, middle deltoid and flexor carpi radialis acted to stabilize the rider’s neck, scapula and wrist during impact. In mid-stance, the rectus abdominis stabilized the rider’s trunk and may have allowed the rider to follow the horse’s upward movement by swinging the pelvis forward and upward. The flexor carpi radialis and biceps brachii contracted synchronously in early stance, alternating with the triceps brachii, which contracted in late stance. Their actions may affect rein tension by maintaining the distance between the rider’s hand and the horse’s bit, probably by flexing and extending the elbow joint. The teres major, extensor carpi ulnaris and serratus anterior had tonic activity or were inactive, and their functions may be related to general postural control. These data may be of benefit in designing appropriate strength and conditioning exercises for riders. Further studies are in progress to investigate the relationship between muscle activation patterns and rein tension.

**Acknowledgements**

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**References**