Evaluation of consistency of jumping technique in horses between the ages of 6 months and 4 years

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Objective—To determine whether differences in jumping technique among horses are consistent at various ages.

Animals—12 Dutch Warmblood horses.

Procedure—Kinematics were recorded during free jumps of horses when they were 6 months old (ie, no jumping experience) and 4 years old (ie, the horses had started their training period to become show jumpers). Mean ± SD height of the horses was 1.40 ± 0.04 m at 6 months of age and 1.70 ± 0.05 m at 4 years of age.

Results—Strong correlations were found between values from 6-month-old foals and 4-year-old horses for variables such as peak vertical acceleration generated by the hind limbs (*r*, 0.91), peak rate of change of effective energy generated by the hind limbs (*r*, 0.71), vertical velocity at takeoff (*r*, 0.65), vertical displacement of the center of gravity during the airborne phase (*r*, 0.81), and duration of the airborne phase (*r*, 0.70).

Conclusions and Clinical Relevance—Although there are substantial anatomic and behavioral changes during the growing period, certain characteristics of jumping technique observed in naïve 4-year-olds are already detectable when those horses are foals. (*Am J Vet Res* 2004;65:945–950)

Several studbooks evaluate the jumping ability of potential breeding stallions by having young adult horses perform a number of jumps. In The Netherlands, the Royal Dutch Warmblood Studbook evaluates the jumping ability of 3-year-old Dutch Warmblood horses during multiple jumps of a combination of 3 obstacles. By the time the horses are evaluated at 3 years of age, breeders have already made large investments that will lead to disappointment for many of them because a relatively large fraction of the horses will not pass the test. A method for earlier detection of jumping ability could save substantial amounts of money and make breeding more financially rewarding.

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The question of whether adult performance can be predicted from performance in young horses has been addressed for trotting. In longitudinal studies[1-3] of trotting Dutch Warmblood horses and Shetland ponies in which investigators compared performance of foals with that of those same horses as adults, significant correlations were found for several kinematic variables. In another study,[4] those variables were reportedly indicators of gait quality. It was concluded from those studies that the prediction of quality of trotting in adult horses, as determined on the basis of an evaluation when those horses were young, is indeed possible. It is currently unknown whether jumping performance in adult horses can also be predicted on the basis of an evaluation of jumping performance in those horses when they are foals.

To determine whether it is possible to use certain kinematic or kinetic variables measured in foals for the prediction of their jumping performance as adult horses, several steps are required. First, it should be established that the variation in kinematic or kinetic variables within a horse is less than the variation among horses. If this is not the case, selection will not be possible by use of these variables. Second, there must be a substantial correlation between the values of these variables measured in horses when they are foals and adults. Third, it must be documented that these variables are related to talent and cannot be easily influenced by the effects of training; the influence of training effects would lessen the importance of the inherent capacity of the horses. In another study[5] conducted by our laboratory group, we documented that the within-horse variation for several variables related to the jumping technique in a group of naïve 4-year-old show jumpers was less than the variation among horses. There was large variation among horses for the height to which they projected their **center of gravity (CG)**. This variation could be explained to a large extent by the variation in **vertical velocity of the CG ($\dot{y}_{CG}$)** at takeoff, which emerged as a critical and discriminative variable.[5] Horses that had greater $\dot{y}_{CG}$ at takeoff left the ground farther before the fence and landed farther beyond the fence, attained greater maximal **height of the CG (y_{CG})**, had a shorter push-off phase, and generated greater **vertical acceleration of the CG ($\ddot{y}_{CG}$)**, which was primarily during hind limb push.

The purpose of the study reported here was to determine whether these differences in jumping technique among horses were consistent for various ages. We compared kinematic and kinetic data collected from naïve horses during free jumping a fence when they were 4 years old[5] with similar data collected from the same horses when they were 6 months old.[6]

Materials and Methods

Animals—Twelve Dutch Warmblood horses owned by the Institute for Horse Husbandry in Lelystad, The Netherlands, were used for the study. They were part of a larger group of horses used to study the development of jumping technique and the effects of training on jumping performance.[5,6]

Training—The horses were weaned when they were 4 months old. At 6 months of age, they were monitored when jumping a fence that was 0.60 m in height. Subsequently, they were conventionally raised on pasture during the spring and summer and maintained in loose housing during the autumn and winter. When the horses were 36 months old, they began a 4-week period of initial training. Subsequently, the horses were transported to the Dutch Training Center at Deurne, The Netherlands, where they received training in elementary dressage and jumping during a 5-week period, which mimicked the conventional procedures used in the Dutch horse industry. The horses were then sent back to pasture for 6 months, and they subsequently returned to the training center when they were approximately 44.5 months old to start a 1-year period of intensive training in show jumping. The data set for the naïve 4-year-old show jumpers in the study was collected 14 weeks after their return to the training center at a time when the horses had jumped only a few times with a rider over fences that were 0.60 m in height.

Experimental protocol—For horses at 6 months of age and 4 years of age, kinematic data were collected during jumping over a vertical target fence positioned on a jumping track. The horses were familiarized with the jumping conditions by having them practice free jumps in the experimental setting a few times prior to the day of actual measurements.

Details of the arrangements for obtaining measurements have been published elsewhere.[5,6] To obtain measurements, kinematic markers were attached to the left side of the body of each horse (**Figure 1**). These markers were monitored during jumping by use of infrared cameras[a] operating at 240 frames/s. Measurements of the 6-month-old foals were obtained by use of 3 infrared cameras, whereas 6 infrared cameras were used for measurements of the 4-year-old horses. The cameras were placed in a semicircle facing the target fence such that the field of view included the last canter stride before the target fence, the jump over the fence, and the first canter stride after the fence. The target fence was a vertical fence 0.60 m in height for the 6-month-old foals and 1.05 m in height for the 4-year-old horses. These heights were chosen to ensure that all horses, including those that were the poorest jumpers, could jump the target fence without too much difficulty.

To prevent the 6-month-old foals from approaching the fence too fast, a cross-pole fence was placed 5 to 6 m before the target fence; the distance was chosen such that the foals were restricted to making 1 canter stride in between the cross-pole fence and target fence. For the 4-year-old horses, 2 vertical fences preceded the target fence. The first vertical fence was placed 6.4 m from the second vertical fence, which was placed 7.0 m from the target fence. These distances restricted the horses to 1 canter stride between fences. The arrangement for the 4-year old horses was similar to that used by the Royal Dutch Warmblood Studbook in their standard procedures for evaluation of the jumping ability of 3-year-old horses during selection events.

Data collection and analysis—Time course of the marker coordinates was smoothed by use of a fourth-order, zero-lag Butterworth filter with a cutoff frequency of 6 Hz; smoothed data were used to calculate the time course for the x- and y-coordinates of the CG of each horse in accordance with a segmental model defined in another study.[7] Because we were not able to find information on the percentages of total weight of the segments of the body of a foal in the literature, we used a model for adult horses to calculate the position of the CG in foals. Markers were placed only on the left side of the body with the assumption that the right and left extremities of a horse would move symmetrically. This introduced errors, but these errors were assumed to be small because most of the weight of a horse is located in the trunk. Time courses of the CG coordinates were differentiated to yield the CG velocities and CG accelerations.

To avoid fatigue in foals, the number of jumps for each foal was limited to 5. Because many jumps were unsuccessful as a result of nervousness and inexperience of the foals or because of technical problems regarding marker tracking, only 2 to 4 jumps of each foal were usable. We decided to use only the highest jump for each foal, regardless of the leading limb during the approach stride. Adult horses performed 10 to 15 jumps. In another study[5] conducted by our laboratory

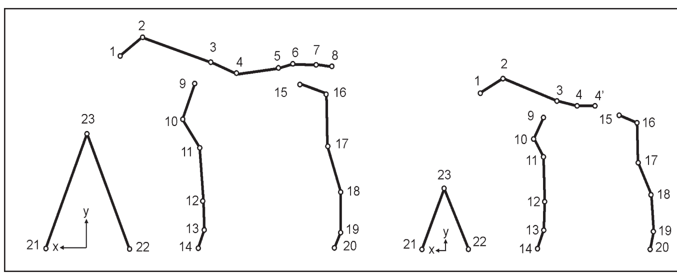

Figure 1—Illustration of the sites at which markers were affixed to anatomic landmarks on each horse at the age of 4 years (left) and 6 months (right) and to a fence. Locations were as follows: 1, crista facialis; 2, atlas; 3, top of the shoulders (ie, spinous process of T6); 4, spinous process of T13; 4' spinous process of L1; 5, spinous process of L2; 6, L5; 7, S2; 8, S5; 9, spine of the scapula; 10, center of rotation for the scapulohumeral joint; 11, center of rotation for the humeroradial joint; 12, carpus; 13, center of rotation for the metacarpophalangeal joint; 14, hoof of the forelimb; 15, tuber coxae; 16, center of rotation for the coxofemoral joint; 17, center of rotation for the femorotibial joint; 18, tarsus; 19, center of rotation for the metatarsophalangeal joint; 20, hoof of the hind limb; 21, ground 1; 22, ground 2; and 23, top of the fence. At the age of 4 years, markers were also attached on the medial aspect of right limbs (not shown).

Table 1—Mean ± SD values for conformation variables in 12 horses when they were 6 months old and 4 years old.

Variable	6 months	4 years	4 years:6 months	(4 years:6 months)^3	*r**
Height (m)	1.40 ± 0.04	1.70 ± 0.05	1.21	1.77	0.51
Length (m)	1.07 ± 0.05	1.38 ± 0.05	1.29	2.15	0.54
Body weight (kg)	262 ± 31	619 ± 43	2.36	13.14	0.67*

*Represents the Pearson correlation coefficient between the values at 6 months of age and 4 years of age. Height was measured as the vertical distance from the top of the shoulders to the ground. Length represents length of the trunk and was measured as the horizontal distance between the markers affixed to the left shoulder and left hip. Height and length were measured when the horses were in a standing position.

group, we selected 4 jumps during which the horse approached the target by leading with the left forelimb; we found that the variation among jumps was extremely small. For the study reported here, we used only the highest jump of each adult horse for analysis, similar to the situation for the foals. For each variable, we confirmed that results were almost identical when we used the mean value for the 4 jumps or the value of only the highest jump.

Table 2—Mean ± SD values for kinematic and kinetic variables during free jumping in 12 horses when the horses were 6 months and 4 years old.

Variable	Exact moment	6 months	*r**	4 years	*r**	*r*†
y_{CG}	Standing horse (m)	1.20 ± 0.04	0.22	1.43 ± 0.05	–0.45	0.35
	Transition (m)	1.20 ± 0.04	0.10	1.44 ± 0.06	–0.69‡	0.13
	Takeoff (m)	1.32 ± 0.06	0.60‡	1.74 ± 0.05	–0.06	–0.06
	Forelimb clearance (m)	1.28 ± 0.10	0.57	1.78 ± 0.09	0.78§	0.68‡
	Apex of jump (m)	1.42 ± 0.08	0.80§	1.94 ± 0.08	0.82§	0.33
	Hind limb clearance (m)	1.36 ± 0.07	0.69‡	1.91 ± 0.10	0.86§	0.41
$\Delta y_{CG,air}$	Apex of jump (m)	0.10 ± 0.03	0.93§	0.20 ± 0.07	0.97§	0.81§
$\dot{y}_{CG}$	Transition (m/s)	–0.21 ± 0.27	0.14	1.17 ± 0.24	0.87§	–0.05
	Takeoff (m/s)	1.29 ± 0.22	1.00§	1.93 ± 0.36	1.00§	0.65‡
$\ddot{y}_{CG}$	Peak during hind limb push (m/s^2)	19.17 ± 3.48	0.55	13.56 ± 2.09	0.78§	0.91§
$\dot{E}_{eff}$	Peak during hind limb push (W/kg)	24.83 ± 5.97	0.95§	40.71 ± 10.24	0.99§	0.71§
x_{CG}	Transition (m)	–1.53 ± 0.32	–0.57	–1.69 ± 0.17	–0.37	0.27
	Takeoff (m)	–0.52 ± 0.28	–0.60‡	–0.54 ± 0.20	–0.61‡	0.39
	Apex of jump (m)	0.31 ± 0.26	–0.27	0.77 ± 0.21	0.70§	0.30
	Landing (m)	0.87 ± 0.28	0.39	2.00 ± 0.42	0.92§	0.68§
$\dot{x}_{CG}$	Initial (m/s)	5.70 ± 0.42	0.48	7.76 ± 0.40	0.52	–0.05
	Takeoff (m/s)	5.78 ± 0.55	0.04	6.82 ± 0.34	0.47	0.19
Forelimb($y_F - y_0$)	Forelimb clearance (m)	0.31 ± 0.09	0.75§	0.18 ± 0.07	0.12	0.44
Hind limb ($y_F - y_0$)	Hind limb clearance (m)	0.35 ± 0.15	0.77§	0.20 ± 0.07	0.43	0.53
Forelimb length	Forelimb clearance (m)	0.54 ± 0.05	–0.25	0.62 ± 0.11	0.52	0.26
Hind limb length	Hind limb clearance (m)	0.73 ± 0.07	–0.07	0.77 ± 0.10	0.13	0.14
Duration of hind limb push (s)	—	–0.18 ± 0.02	0.22	–0.19 ± 0.02	0.84§	–0.27
Duration of airborne phase (s)	—	0.23 ± 0.05	0.96§	0.40 ± 0.07	0.93§	0.70‡

*Represents the Pearson correlation coefficient within each age group between vertical velocity of the center of gravity ($\dot{y}_{CG}$) at and the indicated variable.

†Represents the Pearson correlation coefficient between values obtained for each variable at 6 months of age and 4 years of age. ‡Correlation is significant ($P < 0.05$; 2-tailed test). §Correlation is significant ($P = 0.01$; 2-tailed test).

y_{CG} = Height of the center of gravity (CG). Transition = Transition between forelimb push and hind limb push; it is defined as the exact moment that vertical acceleration of the CG ($\ddot{y}_{CG}$) reaches a local minimum. Takeoff = Exact moment that $\ddot{y}_{CG}$ becomes –9.81 m/s^2. Forelimb clearance = Exact moment that the metacarpophalangeal (ie, fetlock) joint of the left forelimb is over the top of the fence. Apex of jump = Exact moment that y_{CG} is maximal. Hind limb clearance = Exact moment that the metatarsophalangeal (ie, fetlock) joint of the left hind limb is over the top of the fence. $\Delta y_{CG,air}$ = Vertical displacement of the CG in the airborne phase; this value was calculated by subtracting y_{CG} at takeoff from the maximal y_{CG}. $\dot{E}_{eff}$ = Rate of change of effective energy; it is calculated as the sum of potential energy and kinetic energy attributable to $\dot{y}_{CG}$. x_{CG} = Horizontal distance from the CG to the top of the fence; this distance has a negative value when a horse is approaching the fence. Landing = Exact moment that $\ddot{y}_{CG}$ stopped being –9.81 m/s^2 at the end of the airborne phase. $\dot{x}_{CG}$ = Horizontal velocity of the CG. Initial = Exact moment that the right forelimb impacts the ground. Forelimb ($y_F - y_0$) = Vertical distance between the fetlock joint of the left forelimb and the top of the fence. Hind limb ($y_F - y_0$) = Vertical distance between the fetlock joint of the left hind limb and the top of the fence. Forelimb length = Linear distance between the left front fetlock and left shoulder. Hind limb length = Linear distance between the left hind fetlock and left hip. Duration of hind limb push = Interval from transition to takeoff. Duration of airborne phase = Interval from takeoff to landing. — = Not applicable.

Variables selected for analysis were calculated at the exact moment during the jump for transition between the forelimb push and hind limb push, takeoff, forelimb clearance, apex of the jump, hind limb clearance, and landing. To detect the exact moment of takeoff, we found the exact moment at which $\ddot{y}_{CG}$ decreased to 0, fit a straight line to the **time history of** $\ddot{y}_{CG}$ ($\ddot{y}_{CG}$[t]) around this exact moment, and extrapolated this line to the exact moment that $\ddot{y}_{CG}$ became -9.81 m/s^2. This ensured that small oscillations in $\ddot{y}_{CG}$(t) that were evident in a few jumps had only a negligible effect on detection of the exact moment of takeoff. A similar procedure was used to detect the exact moment of landing, signifying the end of the airborne phase. Apex of the jump was defined as the exact moment that y_{CG} became maximal. Finally, the exact moment of clearance of the forelimbs was defined as the exact moment at which the marker on the left metacarpophalangeal (ie, fetlock) joint was directly over the top of the fence, whereas the exact moment of clearance with the hind limbs was defined as the exact moment at which the marker on the left metatarsophalangeal (ie, fetlock) joint was directly over the top of the fence.

Statistical analysis—Pearson correlation coefficients were calculated by use of commercially available software.[b] Correlations were calculated for selected combinations of variables within each age group and for the values of each variable between age groups.

Results

Conformation of the 12 horses when they were 6-month-old foals and 4-year-old adults was summarized **(Table 1)**. The horses increased in height and length (21% and 29%, respectively), whereas the increase in body weight was 136%.

Considerable variation was found among the horses for y_{CG} at the apex of the jump. This variable depends on y_{CG} at takeoff and $\dot{y}_{CG}$ at takeoff. For the 4-year-old horses, y_{CG} at the apex of the jump had a low correlation (*r*, 0.49) with y_{CG} at takeoff but a much stronger correlation (*r*, 0.82) with $\dot{y}_{CG}$ at takeoff. For the 6-month-old foals, y_{CG} at the apex of the jump was strongly correlated with y_{CG} at takeoff (*r*, 0.95) and $\dot{y}_{CG}$ at takeoff (*r*, 0.80). In turn, y_{CG} at takeoff was correlated (*r*, 0.82) with standing y_{CG}, suggesting that foals that reached a high y_{CG} at the apex of the jump were large foals. However, after adjusting for standing y_{CG} in the foals, there was only a slight reduction in the correlation between y_{CG} at the apex of the jump and y_{CG} at takeoff (*r*, 0.90), whereas the correlation between y_{CG} at the apex of the jump and $\dot{y}_{CG}$ at takeoff (*r*, 0.94) was slightly increased. For 4-year-old horses, the correlation between y_{CG} at the apex of the jump and y_{CG} at takeoff (*r*, 0.72) was less than the correlation between y_{CG} at the apex of the jump and $\dot{y}_{CG}$ at takeoff (*r*, 0.92), suggesting that for this age group, $\dot{y}_{CG}$ was the variable causing most of the variation in y_{CG} at the apex of the jump. Therefore, we decided to focus on this variable for the analysis of both age groups.

Comparing the sets of kinetic and kinematic data collected from the horses when they were 6-month-old foals and 4-year-olds revealed that some variables had high correlations **(Table 2)**. Correlations were highest for the peak of $\ddot{y}_{CG}$ during the hind limb push (*r*, 0.91), peak of **rate of change of effective energy ($\dot{E}_{eff}$)** during the hind limb push (*r*, 0.71), vertical displacement of the CG (*r*, 0.81), and duration of the airborne phase (*r*, 0.70). Somewhat lower but still significant correlations (values of *r* that ranged from 0.60 to 0.70) were found for $\dot{y}_{CG}$ at takeoff and the horizontal distance from the fence at landing **(Figure 2)**.

To illustrate the consistency of differences among horses between age groups, we selected the horse that had the highest $\dot{y}_{CG}$ at takeoff and the horse that had the lowest $\dot{y}_{CG}$ at takeoff and plotted representations of these horses at both ages during various phases of a jump **(Figure 3)**. At 6 months of age and 4 years of age, these 2 horses approached the fence by leading with their left forelimb. At 6 months of age and 4 years of age, the horse

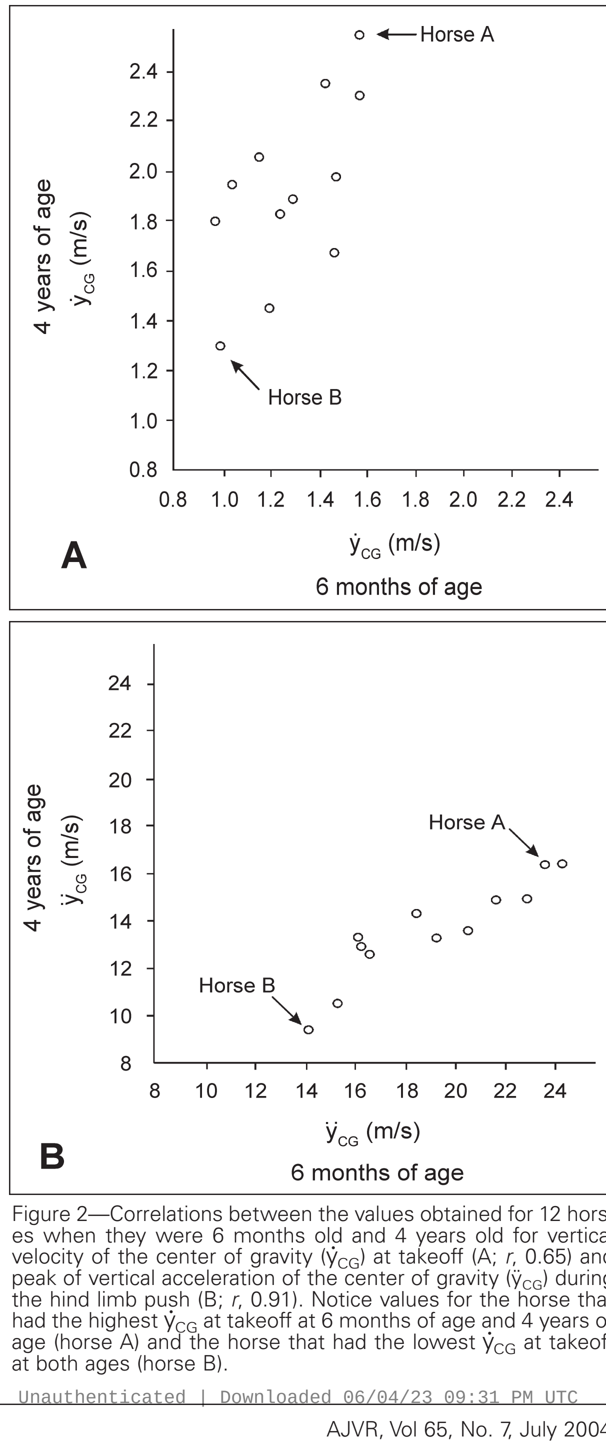

Figure 2—Correlations between the values obtained for 12 horses when they were 6 months old and 4 years old for vertical velocity of the center of gravity ($\dot{y}_{CG}$) at takeoff (A; *r*, 0.65) and peak of vertical acceleration of the center of gravity ($\ddot{y}_{CG}$) during the hind limb push (B; *r*, 0.91). Notice values for the horse that had the highest $\dot{y}_{CG}$ at takeoff at 6 months of age and 4 years of age (horse A) and the horse that had the lowest $\dot{y}_{CG}$ at takeoff at both ages (horse B).

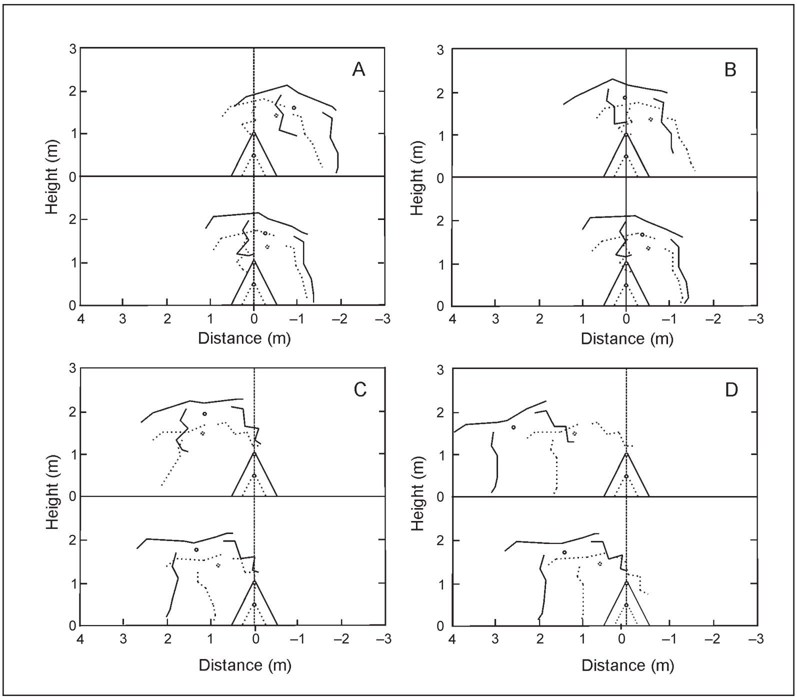

Figure 3—Illustrations of the typical jumps of a horse with the highest $\dot{y}_{CG}$ at takeoff (top of each panel) and a horse with the lowest $\dot{y}_{CG}$ at takeoff (bottom of each panel) plotted at the exact moment of takeoff (A), forelimb clearance (B), hind limb clearance (C), and landing (D) during a jump performed when the horses were 6 months (dashed line) and 4 years (solid line) of age. These are the same horses identified in Figure 2. The center of gravity of each horse is indicated (dot).

with the highest $\dot{y}_{CG}$ at takeoff left the ground farther before the fence and landed farther beyond the fence, compared with the horse with the lowest $\dot{y}_{CG}$ at takeoff. In addition, at the exact moment of forelimb clearance, the horse with the highest $\dot{y}_{CG}$ at takeoff was already in the airborne phase, whereas the horse with the lowest $\dot{y}_{CG}$ at takeoff was still pushing off with the hind limbs. At the exact moment of hind limb clearance, the horse with the highest $\dot{y}_{CG}$ at takeoff was still in the airborne phase, whereas the horse with the lowest $\dot{y}_{CG}$ at takeoff had already landed.

Discussion

Changes in conformation from 6 months to 4 years of age were substantial (Table 1). The finding that length of the trunk increased by 29% but height at the top of the shoulders increased by only 21% is in accordance with the fact that foals are relatively long-legged animals. Body weight of the 4-year-old horses was more than twice that of the foals. Body weight is determined primarily by the weight of the trunk, which accounts for 65% of total body weight. Similarity between the ratio of the body weight of 4-year-old horses and 6-month-old foals (2.36) and the cubed value for the ratio of the trunk (2.15) documents that the trunk of horses grows allometrically. This finding supports our presumption that no substantial error was introduced by use of the segmental model developed for adult horses[7] during calculation of the motion of the CG of foals.

Accuracy of the calculations of the motion of the CG was addressed in another study[5] in which our laboratory group compared 2 estimates of the vertical displacement of the CG after takeoff (1 calculated directly from positional data and the other predicted from the $\dot{y}_{CG}$ at takeoff). In the study reported here, the mean values obtained for those 2 estimates for the 4-year-old horses were 0.198 and 0.196 m, respectively, and were highly correlated (*r*, 0.98), whereas those mean estimates obtained for the foals at 6 months of age were 0.100 and 0.090 m, respectively, which were also highly correlated (*r*, 0.95). On the basis of this outcome, it appears safe to assume that the method of calculating the estimates of CG position and its derivatives was sufficiently accurate.

For foals and 4-year-old horses, greater $\dot{y}_{CG}$ at takeoff was accompanied by a greater peak of $\dot{E}_{eff}$ during the hind limb push. Moreover, a higher $\dot{y}_{CG}$ at takeoff resulted in a greater duration of the airborne phase. In turn, because variation in horizontal velocity of the CG at takeoff was small, those horses jumped a greater distance. At 4 years of age, the horses with a higher $\dot{y}_{CG}$ at takeoff left the ground farther from the fence to enable them to position the apex of the jump close to the top of the fence.

From the study reported here, it becomes clear that although substantial anatomic and behavioral changes were evident during the growing period, unique characteristics observed in the jumping technique of naïve 4-year-old horses were already recognizable in those horses at 6 months of age. The strongest correlation coefficient between data from foals and 4-year-old horses was found in the peak of $\ddot{y}_{CG}$ during the hind limb push. Horses that generated the highest peak of $\ddot{y}_{CG}$ during the hind limb push when they were foals were the same ones that had the highest peak of $\ddot{y}_{CG}$ during the hind limb push at 4 years of age when they were at the start of their show jumping career. This finding could be of importance when linked with results obtained in another study[8] in which investigators measured ventrodorsal acceleration in two hundred 3-year-old horses during free jumping in selection events that took place in France. When comparing the acceleration data with the final ranking obtained in that study, those investigators found that good jumpers had higher peak ventrodorsal acceleration during the hind limb push and higher $\dot{y}_{CG}$ at takeoff, compared with values for poor jumpers.

The fact that significant correlations were found in the study reported here for variables that are considered important for jumping performance[9,10] suggests that the jumping technique of foals may yield clues about the potential for show jumping when they become adult horses. It would be tempting to predict, for example, that the horse with the highest $\dot{y}_{CG}$ at takeoff would develop into a better show jumper than the horse with the lowest $\dot{y}_{CG}$ at takeoff (Figure 2). However, such a prediction would be premature for several reasons. First, the horses were not jumping to their maximum height; thus, the peak of $\ddot{y}_{CG}$ during the hind limb push measured in each of these horses may not have been the maximum value these horses could generate. Second, it cannot be excluded that some horses will benefit more from training than other horses or will be more susceptible to the guidance of a rider, which could reduce the correlations between variables for foals and adult horses. Therefore, it is premature to conclude that it is possible to select talented show jumpers on the basis of their jumping performance as foals. However, we will continue to monitor the performance of the horses participating in this study, and once their performance in actual competitions is known, we can hopefully provide more information about the prediction of performance as an adult on the basis of performance as a foal.

[a]Pro Reflex, Qualisys Medical AB, Göteborg, Sweden.
[b]SPSS version 10.0 for Windows, SPSS Inc, Chicago, Ill.

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