

Do back kinematics of elite horses change over consecutive days of jumping the same course?

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Summary: Show jumping kinematics at take-off, during flight and at landing has been investigated but has mainly focused on the limbs; there has been limited investigation of the back during jumping. However one study indicated that there are considerable differences in back kinematics between good and poor jumpers suggesting that back kinematics are important for jumping performance. The objective of this study was to evaluate head, neck and back kinematics of elite horses during take-off jumping an upright and parallel spread fence over two consecutive days of jumping the same course. Ten mixed breed elite level showjumping horses were opportunistically evaluated jumping the same 15 fence course (1.35 m) during a British Equestrian Federation World Class Performance three-day training session. Two fences were evaluated using high-speed motion-capture (250 Hz). Head, neck and back kinematics of the horse were determined at take-off, at vertical orientation of leading and trailing third metacarpus/tarsus, hindlimb to forelimb suspension phase and as the trailing hindlimb left the floor. The results showed that certain movement features were repeatable between days (HN, NT and LSHorz angle). There were also differences observed, suggesting that not all movement patterns were consistent between days. No differences were observed between the upright and parallel spread fence and speed was not significantly different between days. Our findings suggest that specific features of the horse's neck and back angles are not repeatable even over successful jumping efforts of the same fences within the same course over two consecutive days of jumping. These findings could have an influence on many aspects of performance and potentially influence scientific measurement protocols.

Keywords: equine, show jumping, take-off, kinematics, neck, thoracolumbar

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Introduction

Showjumping kinematics at take-off, flight and landing have been investigated (Barrey and Galloux 1997, Barrey and Langlois 2000, Bobbert et al. 2005, Cassiat et al. 2004, Clayton 1989, Clayton and Barlow 1989, 1991, Clayton et al. 1995, Deuel and Park 1991, Falturi et al. 2001, Godoi et al. 2014, 2016, Hernlund et al. 2010, Lütteken 2001, Powers 2002, Powers and Harrison 2000, 2002, Powers and Kavanagh 2005, Santamaria et al. 2004, Wejer et al. 2013) and these investigations have mainly focused on limb kinematics and/or ground reaction forces (Clayton and Barlow 1991, Meershoek et al. 2001a, 2001b). There has been limited evaluation of the back during jumping (Cassiat et al. 2004, Godoi et al. 2014, 2016, Santamaria et al. 2004, Wejer et al. 2013) but these studies have shown there are considerable differences between good and poor jumpers indicating that back kinematics can be important for jumping performance.

Terminology of the jump events have been defined to enable consistent description of jumping biomechanics (Clayton 1989, Clayton and Barlow 1989). Several studies have highlighted the importance of take-off (Hay 1985, Powers and Harrison 1999, 2002) and its impact on the rest of the jump

sequence in terms of providing suitable body positioning, velocity and angular momentum to clear the fence (Powers and Harrison 1999). In loose jumped horses the height and distance of the centre of gravity (CG) (Murariu 2014, Powers and Harrison 1999, 2000) and hindlimb distance from the fence at take-off have been identified as being important factors which affect the outcome of the jump (Bobbert et al. 2005, Clayton and Barlow 1991, Denoix and Audigie 2001, Van den Bogert et al. 1994). These are influenced by the head, neck and back angles and trunk inclination to the horizontal at take-off (Denoix 2014, Denoix and Audigie 2001, Godoi et al. 2014, 2016, Santamaria et al. 2004). The forward motion of the trunk segment, along with its upward rotation, are vital for the horse to be able to get high enough to clear the fence (Cassiat et al. 2004) so understanding back movement can aid our understanding of desirable characteristics of performance. These previous studies may have tested horses in several conditions over multiple days but to the authors' knowledge repeatability over consecutive days has not been reported. Given that International showjumping competitions and championships frequently include jumping over consecutive days, studies evaluating how showjumping kinematics may change over time for elite horses would be of interest and add to the current literature.

Trunk-based accelerometer data found that each horse has its own individual jump technique that is repeatable jump to jump, around a single course of fences (Barrey and Galloux 1997). Van den Bogert et al. (1994) found that a group of elite showjumping horses jumping a 1.50m vertical had a similar movement pattern at take-off. It could therefore be expected that a group of elite horses would have repeatable movement patterns in the final approach and take-off jumping the same course over two consecutive days.

The aim of the study was to evaluate the consistency of horse head, neck and back angles at take-off in elite level horses over two consecutive days. It was hypothesised that there would be no significant differences in horse head, neck and back angles in the final approach stride and at take-off or in take-off distance between days.

Materials and Methods

Horses and riders

Ten mixed breed elite level showjumping horses, ridden by five riders, were evaluated at a British Equestrian Federation World Class Performance three day training camp. All horses and riders were classed as elite as they were regularly competing at 140cms and above. All horses were evaluated by an orthopaedic specialist (RCM) on each day of the training camp and all were assigned < 1/8 lameness grade (Dyson 2011) when walking and trotting in a straight line on hard and soft surfaces. All horses were ridden by their normal rider and each day riders were given up to 40 minutes to warm-up. Riders were instructed to warm-up as if they were at a competition, prior to jumping a 15 fence course on a waxed sand and fibre surface. Mean warm-up duration was 18 minutes. Further details can be seen in Tranquille et al. (2017). All horses jumped the course once on day 1 (D1), twice on day 2 (D2) and once on day 3 which was followed by a shorter jump-off style course. Data from D1 and round 1 on D2 is presented here. The rider-horse sequence was the same on all days and there was 24 hours between each jump round. Further information can be found elsewhere (Walker et al. 2018). Horses wore spherical, 30mm-diameter markers at pre-determined palpable surface landmarks (Ashdown and Done 2011). Information on marker placement and marker placement repeatability can be found elsewhere (Walker et al. 2018).

Data Collection

High-Speed Video

Two fences, 12b (upright fence) and 12c (parallel spread fence) which were part of a triple combination, one non-jumping stride (7.5 m) apart, were evaluated and high-speed video footage was collected using two Olympus i-Speed cameras (Olympus Europa, Hamburg, Germany) mounted upon an adjustable tripod. Images were recorded at 250 Hz parallel to the fence, with the centre of the fence positioned in the centre of the field of view (FOV). The FOV was 5.21 m for fence 12b and 5.24 m for fence 12c. The camera was calibrated using

the length of the base of the wing nearest the camera and the cranial aspect of the zygomatic ridge to the atlas on the horse in the frame of measurement. These were both used to ensure the calibration was accurate to 0.5mm. Distance of the camera to the fence was 3m from the middle of the fence and was marked on the floor for consistent placement. Arena set-up and fence height and width can be seen elsewhere (Walker et al. 2018).

Data Analysis

Images acquired were analysed by an experienced analyst (VAW) using digital image analysis software (Pro Analyst, Xcitem, USA). Repeatability of marker tracking was determined by tracking all markers and derived angles three times in five horses. A coefficient of variance of < 3% was determined and deemed acceptable based on previous studies (Walker et al. 2013a, 2013b, 2016, 2017, 2018).

Head neck (HN), neck trunk (NT), thoracolumbar (TL) and lumbosacral (LS) angle (Fig. 1A), and neck angle to the horizontal (NHorz), thoracolumbar angle to the horizontal (TLHorz) and lumbosacral angle to the horizontal (LSHorz) (Fig. 1B) were measured at the five following instants during the intermediate stride (Hole et al. 2002): 1. when the leading third metacarpal bone (MCIII) was vertical, 2. when the trailing MCIII was vertical; 3. at hindlimb to forelimb, defined as



Fig. 1A Horse angles measured at each stride point. 1) Head and neck angle, 2) Neck trunk angle, 3) Thoracolumbar angle, 4) Lumbosacral angle. | Gemessene Winkel in den verschiedenen Schrittabschnitten. 1) Kopf-Nacken-Winkel 2) Nacken-Brustkorb-Winkel 3) Thorakolumbaler Winkel 4) Lumbosakraler Winkel.



Fig. 1B Horse angles to horizontal at each stride point. 1) Neck to horizontal (NHorz), 2) Thoracolumbar angle to horizontal (TLHorz), 3) Lumbosacral angle to horizontal (LSHorz). | Gemessene Winkel im Vergleich zur Horizontalen in jedem Schrittabschnitt. 1) Nacken zur Horizontalen 2) Thorakolumbaler Winkel zur Horizontalen 3) Lumbosakraler Winkel zur Horizontalen.

the last frame just before hindlimb makes ground contact for the take-off stride, 4. when the leading third metatarsal bone (MTIII) was vertical, and 5. when the trailing MTIII was vertical (Walker et al. 2018). Distance to the fence was measured at all five stride points from the cranial aspect of the toe to the bottom of the fence. Speed was measured from the marker placed above the tuber sacrale. Measurements were accurate to 2.5 mm. Data were calculated from the location of the markers. Processing for skin displacement was not undertaken.

Statistical analysis

Descriptive statistics were used to evaluate initial data patterns and to determine the data distribution. Unsuccessful jumping efforts were excluded from the analysis. On D1 one parallel spread was excluded (Horse 5 (H5)) and on D2 one upright and one parallel spread was excluded (both H5). Our initial comparison analysed all variables for upright vs parallel spread data by a paired test (Students t-test or Wilcoxon signed rank test as appropriate). There were no significant differences between upright and parallel spread for any of the variables measured for D1 or D2, therefore data for both fence types were pooled for further analysis. Differences between days were evaluated by a paired Students t-test or Wilcoxon signed rank test, as appropriate. For all variables comparisons were made for D1 vs D2. Data were analysed using a statistical software package (Analyse-It version 2.26, Leeds, UK) with a significance level of $P < 0.05$.

Results (Table 1)

MCIII vertical instant during the intermediate stride – leading and trailing

There were no significant differences in HN, NT, TL, NHorz, TLHorz and LSHorz ($P \geq 0.05$) but LS angle and distance to the fence were significantly smaller on D1 compared to D2 when the leading MCIII was vertical ($P = 0.003$ and 0.03 respectively). There were no significant differences in any measured variable when the trailing MCIII was vertical ($P \geq 0.05$).

Hindlimb to Forelimb instant during the intermediate stride

There were no significant differences in HN, NT, LS, TLHorz, LSHorz and distance to the fence between D1 and D2 ($P \geq 0.05$). NHorz was reduced and a greater TL angle was observed on D1 compared to D2 ($P = 0.01$ and 0.04 respectively).

MTIII vertical instant during the intermediate stride – leading and trailing

There were no significant differences in HN, NT, TL, LS, NHorz, LSHorz and distance to the fence between D1 and D2 for either leading or trailing MTIII ($P \geq 0.05$). A significantly smaller TLHorz was observed on D1 compared to D2 when

both leading and trailing MTIIIs were vertical ($P = 0.003$ and 0.03 respectively).

Speed

There were no significant differences between days for the upright or parallel spread fence ($P > 0.05$). For the upright fence mean speeds on D1 mean \pm sd were $= 3.9 \pm 0.4$ m/s and on D2 $= 4.2 \pm 0.9$ m/s. For the parallel fence mean speeds on D1 mean \pm sd were $= 4.3 \pm 0.4$ m/s and on D2 $= 4.4 \pm 0.7$ m/s.

Discussion

The results showed that although certain movement features were repeatable between days, there were also differences observed suggesting that not all movement patterns were consistent between days. Both hypotheses were therefore rejected. This suggests that specific features of the horse's neck and back angles are not repeatable even over successful jumping efforts of the same fences within the same course over two consecutive days of jumping. This is in accordance with a previous study using fences of a similar height (Clayton and Barlow 1989).

MCIII vertical point during the intermediate stride – leading and trailing

When the leading MCIII was vertical the only significant differences between days were a smaller LS angle and distance to fence on D1 compared to D2. When the leading MCIII is vertical prior to lift off, the forehand of the horse is lowered to load the muscles, tendons and ligaments associated with the forelimb in preparation for hindlimb propulsion (Denoix 2014). At this point in the stride the trunk is orientated above the limb, as it is in mid-stance in canter on the flat (Crevier-Denoix et al. 2014). The hindlimbs are in retraction and the horse is in an elongated position. The increased LS extension (dorsiflexion) angle would suggest that the horse is more elongated on D2 compared to D1, which would support an increase in distance to the fence (Cassiat et al. 2004). It is not clear from our measurements if one causes another but it may be that either or both could have been influenced by a slightly different approach between days, potentially related to alterations by the rider or horse on the second time of jumping the course. This may be a positive modification; in Olympic level horses it has been observed that faults are less likely to occur when take-off is further from the fence (Deuel and Park 1991). We did not observe changes in HN, TL, NHorz, TLHorz and LSHorz angles when the leading MCIII was vertical and angles were not different when the trailing MCIII was vertical, which suggests they were unaffected by the changes in the other variables and were consistent over two consecutive days of jumping.

Hindlimb to forelimb point during the intermediate stride

A reduction in NHorz and an increased TL extension angle was observed on D1 compared to D2 at this stride point. These findings may be attributed to the neck position at this

point of the stride on D1 compared to D2 resulting in greater TL extension. No changes in other angles were observed. Cassiat et al. (2004) noted greater TL flexion at this point of the stride in 'good jumpers' so it appears that greater TL extension may not be desirable.

MTIII vertical point during the intermediate stride (hindlimb propulsion)

TLHorz was significantly smaller (closer to the horizontal) on D1 compared to D2 when leading and trailing MTIII were vertical. This suggests that the trunk of the horse had a more shallow inclination at this stage of the jump on D1 compared to D2. It is possible that the more shallow positioning may be related to the greater extension (dorsiflexion) of the TL region at hindlimb to forelimb, which could alter the positioning of the TL region to the horizontal once the hindlimbs made ground contact and started to propel the hindlimbs upwards ready for take-off (Cassiat et al. 2004, Leach and Dagg 1983). Three studies (Clayton and Barlow 1995, Colborne et al. 1995, Powers 2002) have shown that trunk angle is an important variable in the take-off to successfully clear a jump suggesting that a 'flatter' trunk angle may not be desirable.

Speed of the intermediate stride did not change between days, which is in accordance with previous findings (Hole et

al. 2002). This is an important factor to consider as speed of the approach could have an impact on kinematics (Robert et al. 2002). It has been suggested that riders can affect the horse's approach speed when jumping compared to their loose jumping speed (Powers and Harrison 2002) and our findings support this. However, a previous study (Powers and Kavanagh 2005) observed no effect of national and novice level rider on approach speed. The fences used in the current study were parts B and C of a three fence combination, which could have contributed to the reduction in variation in speed. HN, NT and LSHorz were the only angles that did not change between days at any of the stride points measured. This suggests that these may be repeatable over two consecutive days of jumping. These variables may be associated with the horse's approach, which is likely to be more consistent in a combination, so may have been influenced by the fences evaluated. In a study evaluating kinematics of three groups of loose jumping horses (Godoi et al. 2014), it was found that kinematics became more consistent as the horse aged. This may be due to training, which could be a consideration in our group of horses. Our findings therefore may not be replicated in lower level, younger or less well-trained show jumpers.

Further work is required to evaluate the consistency of head, neck and back kinematics when jumping different courses between days. In this study there is no evidence to suggest that the horses jumped 'better' on any day as the number of knock

Table 1 Mean and standard deviation for all stride points and for both days of jumping the same course. sd = standard deviation, ° = degrees, HN = Head neck, NT = Neck trunk, TL = Thoracolumbar, LS = Lumbosacral, NHorz = Neck to horizontal, TLHorz = Thoracolumbar to horizontal, LSHorz = Lumbosacral to horizontal, DtF = distance to fence, T = Trailing, L = Leading, HLVert = Hindlimb vertical at stance, FLVert = FL vertical at stance, HL to FL = just before hindlimb ground contact for take-off stride. Significant differences shown in bold. | Mittelwert und Standardabweichung aller Schrittabschnitte an beiden Tagen während des Springens in ein und demselben Parcours: sd = Standardabweichung, 0 = Grad, HN = Kopf-Nacken, NT = Nacken-Brustkorb, TL = Thorakolumbar, LS = Lumbosakral, Nhorz = Nacken zur Horizontalen, TLHorz = Thorakolumbar zur Horizontalen, LSHorz = Lumbosakral zur Horizontalen, DtF = Abstand zum Zaun, T = Hinterkante, L = Vorderkante, HLVert = Hinterbein in vertikaler Haltung, FLVert = Vorderbein in vertikaler Haltung, HL to FL = genau vor Bodenkontakt des Hinterbeins vor dem Absprung gemessen. Bedeutende Unterschiede sind fett dargestellt.

Variable	Day	T HLVert	L HLVert	HL to FL	T FLVert	L FLVert
		Mean ± sd	Mean ± sd	Mean ± sd	Mean ± sd	Mean ± sd
HN angle (°)	1	68 ± 5	68 ± 5	61 ± 4	64 ± 4	68 ± 7
	2	67 ± 9	67 ± 9	62 ± 5	65 ± 5	67 ± 6
NT angle (°)	1	150 ± 8	149 ± 7	103 ± 6	98 ± 7	95 ± 7
	2	150 ± 9	148 ± 11	102 ± 6	98 ± 4	96 ± 6
TL angle (°)	1	192 ± 6	194 ± 5	188 ± 5	189 ± 2	196 ± 3.0
	2	194 ± 4	194 ± 4	185 ± 3	188 ± 5	194 ± 5
LS angle (°)	1	170 ± 6	168 ± 5	158 ± 7	157 ± 4	158 ± 5
	2	170 ± 4	170 ± 5	159 ± 6	157 ± 5	162 ± 6
NHorz (°)	1	18 ± 4	19 ± 4	32 ± 7	33 ± 7.0	30 ± 7
	2	20 ± 6	23 ± 8	38 ± 7	37 ± 7.0	32 ± 7
TLHorz (°)	1	36 ± 3	36 ± 5	18 ± 6	10 ± 1	1 ± 1
	2	38 ± 3	40 ± 3	16 ± 3	9 ± 4	3 ± 4
LSHorz (°)	1	146 ± 3	145 ± 4	148 ± 6	156 ± 5	173 ± 4
	2	146 ± 3	143 ± 4	147 ± 6	156 ± 6	173 ± 7
DtF (cm)	1	159 ± 28	174 ± 31	37 ± 10	180 ± 25	226 ± 48
	2	169 ± 4	193 ± 39	44 ± 7	197 ± 50	264 ± 63

downs was similar each day. The optimum jumping angles for a show jumper over this height of fences are not known so we cannot discuss how well the horse jumped apart from jumping faults. However, from a practical scientific viewpoint the findings of this study were interesting. *Peaham et al. (2004)* suggested that elite level horses were generally more consistent than lower level horses so it may be that we would have different findings in lower level horses. Our findings suggested that the variation in jumping technique between the testing days could influence the results of such protocols indicating that studies proposing to use this method need to be aware of inter-day variation on some horse variables.

Limitations

The study had several limitations. The fences used in this study were part B and C of a triple combination, which may have limited the variation in approach which we deemed as desirable for this study. This does mean that the findings seen here may not apply to the same horses over independent fences. Motion capture was only possible in two-dimensions, meaning rotation movements could not be measured. Another important limitation is that our measurements were calculated from skin-based markers and therefore liable to displacement in moving horses (*Van Weeren 1990*). Using bone fixed markers would not be possible in ridden jumping horses, we were limited to motion capture and image analysis based on skin markers. Therefore the measured angles are potentially crude estimates and this should be kept in mind when interpreting the current findings. We currently do not know how it would differ between two days but the horses' body condition and hydration were similar on both days. Horses were not performing maximal jumping efforts which could limit variation in our data. The data collection was opportunistic as it was carried out at a training session so the horses were preselected and any issues with the cameras or an unsuccessful jumping attempt meant data loss as fences could not be repeated. However, this caused minimal issues in relation to our data collection. The sample size was small which limited the variation within the sample. There could have been a learning/training effect as the course remained the same for both test days. This does not reflect a 'real life competition scenario' where the course changes from class to class, but did allow more consistent comparison to the benefit of this study.

Conclusion

Our findings indicate that HN, NT, LSHorz angle and distance to the fence for any of the stride points measured did not change between days. However, NHorz, TL, TLHorz and LS angle did change between days. This information is currently lacking in the literature and needs to be borne in mind when designing scientific protocols. Further investigation is required to determine if these findings could have an influence on performance in the jumping horse.

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Conflict of interest

None to declare.

Animal Welfare Statement

It was confirmed by the Royal College of Veterinary Surgeons that the procedures carried out were not Controlled Procedures under UK animal experimentation legislation.

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