Equine Veterinary Journal

Equine Veterinary Journal ISSN 0425-1644
DOI: 10.1111/evj.12259

Posture and movement characteristics of forward and backward walking in horses with shivering and acquired bilateral stringhalt

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Summary

Reasons for performing study: To investigate and further characterise posture and movement characteristics during forward and backward walking in horses with shivering and acquired, bilateral stringhalt.
Objectives: To characterise the movement of horses with shivering (also known as shivers) in comparison with control horses and horses with acquired bilateral stringhalt.
Study design: Qualitative video analysis of gait in horses.
Methods: Owners' and authors' videos of horses with shivering or stringhalt and control horses walking forwards and backwards and manually lifting their limbs were examined subjectively to characterise hyperflexion, hyperextension and postural abnormalities of the hindlimbs. The pattern and timing of vertical displacement of a hindlimb over one stride unit was evaluated among control, shivering and stringhalt cases.
Results: Gait patterns of shivering cases were characterised as follows: shivering-hyperextension (-HE, n = 13), in which horses subjectively showed hyperextension when backing and lifting the limb; shivering-hyperflexion (-HF, n = 27), in which horses showed hindlimb hyperflexion and abduction during backward walking; and shivering-forward hyperflexion (-FHF, n = 4), which resembled shivering-HF but included intermittent hyperflexion and abduction with forward walking. Horses with shivering-HF, shivering-FHF and stringhalt (n = 7) had a prolonged swing phase duration compared with control horses and horses with shivering-HE during backward walking. With the swing phase of forward walking, horses with stringhalt had a rapid ascent to adducted hyperflexion of the hindlimb, compared with a rapid descent of the hindlimb after abducted hyperflexion in horses with shivering-FHF.
Conclusions: Shivering affects backward walking, with either HE or HF of hindlimbs, and can gradually progress to involve intermittent abducted hyperflexion during forward walking. Shivering-HF and shivering-FHF can look remarkably similar to acquired bilateral stringhalt during backward walking; however, stringhalt can be distinguished from shivering-HF by hyperflexion during forward walking and from shivering-FHF by an acute onset of a more consistent, rapidly ascending, hyperflexed, adducted hindlimb gait at a walk.

Keywords: horse; movement disorder; neurology; dyskinesia; myopathy

Introduction

Lameness and proprioceptive deficits account for the majority of gait abnormalities reported in horses. There are, however, ill-defined equine movement disorders, such as shivering (also known as shivers) and stringhalt, which can be difficult to diagnose and distinguish from each other or from other disorders, such as fibrotic myopathy and upward fixation of the patella [1–3]. After excluding lameness and ataxia, a diagnosis of shivering or stringhalt is based on clinical impression, because few, if any, specific diagnostic tests exist [1,3,4]. Clear guidelines that distinguish shivering, stringhalt and other movement disorders are lacking, and definitions found in textbooks frequently overlap [1,5]. For example, both shivering and mild cases of stringhalt are described as causing hyperflexion of the hindlimbs when horses walk backwards or turn, without affecting forward walking [3,6]. Furthermore, shivering is described in some cases as causing excessive hindlimb flexion upon walking backwards [5,7,8] and in other cases as reluctance or inability to walk backwards [9–11]. Many owners believe their horses have shivering if the only clinical sign is reluctance to allow manual lifting of a hindlimb. The lack of research into the pathophysiology of movement disorders such as shivering and stringhalt makes an evidence-based diagnosis difficult. Standardised diagnostic criteria for shivering and stringhalt would constitute an important advancement in understanding movement disorders in horses.

As part of an epidemiological study of shivering (A.C.E. Draper *et al.*, unpublished observations), owners submitted a collection of videos of horses with potential movement disorders. The hypothesis for the present study was that a case definition for shivering, distinct from that of stringhalt, could be derived from subjective and objective analysis of a collection of these videos. Diagnosis of stringhalt was based upon qualitative gait analyses, using criteria defined by the authors and, as such, no further diagnostics (e.g. muscle biopsies, scintigraphy or electrodiagnostics) were undertaken. The purpose of the present study was to use these videos combined with archived videos to develop a classification scheme for shivering and to compare hindlimb movement of shivering cases with unaffected control horses and horses with acquired bilateral stringhalt.

Materials and methods

Case recruitment

Owners of horses potentially affected by shivering submitted videos to the Neuromuscular Diagnostic Laboratory (NMDL), University of Minnesota. Informed consent was obtained in each case. Owners were asked to video the horses while they were being led in hand, walking forwards, walking backwards and turning sharply (to the left and right). In addition, owners were asked to lift up each hindlimb manually for a minimum of 10 s. In order to be included in the present study, the videos needed clearly to show the horse performing the entire locomotor evaluation; poor-quality videos were discarded. The owners were not directly provided with a succinct definition of shivering when videos were solicited, but a long description of potential signs was available from the NMDL website. To provide more videos, particularly those of normal horses and stringhalt cases, videos were also solicited from the authors.

Subjective video assessment of stride movement

Videos were assessed by at least 2 investigators (A.C.E.D., S.J.V., T.N.T., J.D.B. and R.M.) for the presence of abnormalities in forward or backward walking, turning and responses to the limbs being lifted. Videos were included for analysis only if both investigators identified unwillingness to walk backwards, with hypertonicity of the muscles in the pelvic limbs causing either hyperflexion or extension of the hindlimb (stifle and hock). The majority of stringhalt cases were previously recorded by authors (T.N.T., J.D.B., R.M. and S.J.V.) and were reviewed by 2 other authors for inclusion in the present study. Inclusion criteria for stringhalt cases was the presence of bilateral exaggerated stifle and hock flexion during almost every forward walk stride [1]. Reluctance to walk backwards was defined as resistance to move in a backward direction when pressure was placed on the horse's brisket. Specific abnormal hindlimb movements during manual lifting of a limb as well as during the forward and backward swing phases of the stride were classified as follows: unilateral or bilateral; consistent (>75% of the steps affected) or intermittent; abducted; and hyperflexed (HF) or hyperextended (HE). In addition, if the detail in the video allowed, facial grimacing, tail elevation, forelimb stretching and muscle fasciculations were recorded if they could be identified in any part of the video.

Semi-quantitative assessment of stride movement

A subset of videos for each definition of shivering and stringhalt could be analysed semi-quantitatively in an attempt to characterise the basic pattern of the swing phase for forward and backward walking in horses with shivering and stringhalt. Inclusion criteria for semi-quantitative analysis included a representative abnormal stride that occurred when the horse was walking on a flat surface for several strides at approximately a 90 degree angle from the camera with the affected limb on the same side as the camera. Videos were excluded if the fore- and hindlimbs could not be visualised, if the most severely affected hindlimb was not closest to the camera, if the horse was out of focus or if the operator was panning/zooming at a time when measurements would be performed. The video capture methods (i.e. camera position relative to the subject, etc.) were not standardised, because this study used videos received from multiple sources.

A simple frame-by-frame video analysis of one representative forward and backward stride of the most severely affected hindlimb (when closest to the camera) in shivering and stringhalt cases, or one randomly chosen hindlimb in control horses, was performed using iMovie[a]. A stride unit was defined as the frame beginning (defined as 0) when the sole was in contact with the ground and ending (defined as 1) with the frame when the sole was on the ground in the same stance position. For forward walking, the stride began when the limb closest to the camera contacted the ground and ended after the swing phase. For backward walking, the stride began with the affected hindlimb on the ground at the point when the opposite hindlimb left the ground and ended after the swing phase of the affected hindlimb. Using the time scale in iMovie, 20 frames that represented 0.05 stride unit increments from 0 to 1 were selected for analysis. In each selected frame, 2 parallel horizontal lines were drawn, one at the level of the ground (determined from stance phase of the ipsilateral forelimb) and one at the level of the sternum. The distance between these lines was used as a vertical reference (Zref) for each frame so that the amount of vertical movement of the hindlimb could be compared between videos. The Zref was measured using computer calliper software (Euclid)[b]. The vertical displacement (ZD) of the affected hindlimb was measured as the distance between the ground line and the toe of the hindlimb (Fig 1). The ZD measurement was replicated 3 times (by the same observer) and an average used for measurement at each fraction of a stride unit. The vertical displacement of the affected limb was then calculated as a percentage for each fraction of a stride unit using the expression mean ZD/Zref × 100. The duration of each stride unit (stride time) was obtained from the time bar of iMovie. To determine the gait patterns throughout the duration of the swing phase at a forward or backward walk, the mean percentage ZD for each group was plotted at each stride unit increment. The area under the curve (AUC) was calculated using Microsoft Excel and compared among the shivering and stringhalt groups for forward and backward walking using a one-way ANOVA (R-Project for Statistical Computing) and Tukey's *post hoc* test. Significance was set at $P<0.05$. As the videos were not standardised for kinematic analysis, statistical comparisons of the gait patterns between groups should be interpreted as semi-quantitative guidelines only.

Fig 1: Still frame of a video demonstrating how measurements were taken for the vertical reference (Zref) line and vertical displacement (ZD) of the left hindlimb.

In addition, the number of strides in the videos in which hyperflexion in the right and left hind occurred during forward and backward walking was calculated and expressed as a percentage.

Results

Subjective video assessment of stride movement

In total, 70 videos were received from owners; 31 horses were diagnosed with shivering, 2 horses were diagnosed with stringhalt, 21 horses had exaggerated hyperflexion only with manual lifting of one or both hindlimbs, 10 horses appeared to exhibit a normal gait, 3 horses had a gait that could not be characterised accurately, and 3 horses had a video of poor quality that precluded evaluation of the horse performing the entire examination. The authors provided additional videos of shivering (n = 13), normal (n = 2) and acquired bilateral stringhalt cases (n = 5).

Based on similarity of stride characteristics, horses were divided into groups as follows (Table 1).

- Standing-HF: exaggerated hyperflexion with manual lifting of one or both hindlimbs. These horses walked forwards and backwards normally (owner, n = 21).
- Shivering-HE: hyperextension of hindlimbs when walking backwards, with normal forward walking or intermittent mild hyperflexion (owner, n = 6; authors, n = 7).
- Shivering-HF: hyperflexion of both hindlimbs when walking backwards, with normal forward walking (owner, n = 21; authors, n = 6).
- Shivering-FHF: hyperflexion of both hindlimbs when walking backwards, with intermittent severe hyperflexion of both hindlimbs with forward walking (authors, n = 4).
- Stringhalt: hyperflexion of both hindlimbs occurring regularly during forward and backward walking (owner, n = 2; authors, n = 5).

Standing-HF: Two females and 19 males, with a mean age of 12.4 ± 4.7 years (range, 6–23 years) and a range of breeds, were included in this group (Table 1; Video S1). Prolonged hyperflexion of one or both hindlimb(s) was seen only when manually lifting the limb, with 19 of 21 horses also abducting the limb. Forward and backward walking was normal. Six horses had signs bilaterally and 15 had unilateral signs (9 of 15 right hind; and 6 of 15 left hind).

TABLE 1: Summary of hindlimb movement based on manual lifting of the limb, backward walking, forward walking and whether signs were seen uni- or bilaterally from reviewing videos of horses diagnosed with shivering or stringhalt

Classification	n	Breeds	Uni- or bilateral	Manual lifting	Backward walking	Forward walking
Standing-HF	21	14 WB 3 Draught 2 TB 2 QH	Unilateral or bilateral	Hyperflexion	Normal	Normal
Shivering-HE	13	11 Draught 1 WB 1 TB/WB	Bilateral	Hyperextension or resistance	Hyperextension consistent	Normal
Shivering-HF	27	9 WB 8 Draught 8 TB 1 TB/WB 1 Unknown	Bilateral	Hyperflexion or resistance	Hyperflexion Abduction intermittent (RH, 54%; LH, 57%)	Normal
Shivering-FHF	4	3 TB 1 WB	Bilateral	Hyperflexion or resistance	Hyperflexion Abduction consistent (RH, 75%; LH, 85%)	Hyperflexion intermittent (RH, 14%; LH, 15%)
Stringhalt	7	5 TB 2 WB	Bilateral*	Normal to hyperflexion	Hyperflexion consistent (RH, 90%; LH, 89%)	Hyperflexion consistent (RH, 85%; LH, 77%)

The mean percentage of strides where right (RH) and left hindlimbs (LH) were seen to be hyperflexed is recorded in parentheses. Abbreviations: FHF = forward hyperflexion; HE = hyperextension; HF = hyperflexion; LH = left hindlimb; RH = right hindlimb. Breeds: QH = Quarter Horse; TB = Thoroughbred; WB = Warmblood. *A criterion for inclusion of stringhalt cases.

Shivering-HE: Nine male and 4 female horses (Table 1), with a mean age of 9.5 ± 4.3 years (range, 4–16 years), showed reluctance to walk backwards accompanied by hindlimb hyperextension (Video S2), with normal forward walking (Fig 2c). During the backward stride, the hindlimbs were placed farther caudally than seemed normal, with a hyperextended hock and stifle (Fig 2d). All horses extended both forelimbs at the initiation of backward walking which, when combined with hindlimb hyperextension, resulted in a stretched saw-horse appearance. After moving backwards for a few strides, horses appeared to move the contralateral fore- and hindlimbs almost simultaneously; horses did not coordinate fore- and hindlimb movements and became reluctant to back, with 12 of 13 horses being unable to complete more than 2–3 strides backwards. The tail head was elevated and the croup steeply sloped during backward walking in all horses. Facial twitching occurred during backward locomotion. Muscle fasciculations over the hindquarters were seen in 10 of 13 horses. Manual lifting of the hindlimbs was not possible in 4 of the horses, and 2 horses would quickly flex the limb slightly, before quickly replacing the limb to the ground. This meant that the owners were not able to pick out the hindfeet or have farrier work conducted on any of these horses.

Shivering-HF: Twenty-seven horses showed normal forward walking (Fig 2e), with signs of hindlimb hyperflexion when walking backwards (Fig 2f) and manually lifting the hindlimb (Video S3). There were 4 females and 23 males, with a mean age of 12.2 ± 4.7 years (range, 4–23 years; Table 1). Signs were bilateral in all cases, although one hindlimb could be more severely affected than the other. During hyperflexion, the hindlimb was abducted and the affected limb would pause in the hyperflexed state before quickly returning to the ground. This occurred on average in 57% (range: 13–100%) of the left and 54% (range: 13–100%) of the right hindlimb strides with backward walking. Upon backing, the tail head was elevated in all but 5 horses (Fig 2f). Additional signs seen during backward walking, which could not be identified clearly in all horses, included muscle fasciculations over the hindquarters and facial twitching. In 8 of the horses, hyperflexion of one hindlimb during backward walking instigated a 2-beat pace or 4-beat backward gait instead of the normal 2-beat contralateral footfall. Manual lifting of a hindlimb was resisted and induced hyperflexion in the opposite hindlimb or eventually the hindlimb being handled. Abduction of the hyperflexed limb appeared to occur in most cases.

Shivering-FHF: Four male horses (Table 1), aged 15.0 ± 4.2 years (range, 10–19 years), had abnormal hyperflexion of both hindlimbs with forward walking (Fig 2g), backward walking (Fig 2h) and manual lifting of the limb (Video S4). These horses had previously shown signs consistent with shivering-HF and had progressed over 1–3 years (followed by S.J. Valberg) to show marked hyperflexion and abduction of both hindlimbs at almost every stride during backward walking. This occurred on average in 75% (range: 57–100%) of the right and 85% (range: 57–100%) of the left hind backward strides. A notable pause occurred with hyperflexion before the limb was returned to the ground. For short periods, one hindlimb was in the swing phase when the opposite hindlimb was paused in hyperflexion, leaving both hindlimbs off the ground and the horse bearing weight solely on its forelimbs. At the initiation of forward walking, marked hyperflexion with abduction of hindlimbs occurred for the first few strides (Fig 3a). After 2 or 3 such strides the horses walked normally unless a change occurred in surface, direction or speed of walking, or if a distraction occurred. On average, the left hind was seen to hyperflex during 23% (range: 11–32%) of the strides with forward walking and in 15% of the right hind strides (range: 5–23%). Tail head elevation was noted in all horses as they walked forwards initially, as well as when walking backwards. Extreme difficulty with manual leg lifting was present to the point where it was impossible for either hindlimb to be lifted up, or if they did allow the limb to be lifted they moved away from the handler and slammed the foot down rapidly.

Hyperflexion in shivering-FHF horses while walking backwards occurred with the limb abducted, the hip less flexed and the distal limb drawn farther caudally than observed in horses with stringhalt (Figs 2h, j; Figs 3a, b).

Stringhalt: There were 3 male and 4 female horses of unknown age with acquired bilateral stringhalt (Table 1; Video S5). The 5 stringhalt cases obtained from authors' archives were believed to be caused by ingestion of *Hypochaeris radicata* or a related plant, whereas the cause of stringhalt in the 2 owner-submitted cases was unknown. Rapid hindlimb hyperflexion occurred bilaterally during the swing phase of forward stride (Fig 2i), with normal forelimb movement. During backward walking, excessive hyperflexion of both hindlimbs occurred during stride (Fig 2j). During some strides in both forward and backward walking, the affected limb would pause hyperflexed without abduction (Fig 3b) before returning to the ground. On average, the left hind was seen to hyperflex during 85% (range: 19–100%) of the strides walking forwards and the right hind 77% (range: 36–100%). On average, the left hind was seen to hyperflex during 89% (range: 75–100%) of the strides walking backwards and the right hind 90% (range: 50–100%). No facial twitching or marked tail head elevation was apparent. All horses were *grade III* or *IV* on the Huntington Grading Scale for stringhalt [6].

Semi-quantitative assessment of stride movement

A subset of 24 videos of horses with shivering and 9 control horses, as well as all 7 horses with stringhalt, were recorded such that further analysis of

Fig 2: Captured frames at peak vertical displacement (ZD) during forward (top row) and backward walking (bottom row) of control horses (a, b) and horses with shivering-hyperextension (shivering-HE; c, d), shivering-hyperflexion (shivering-HF; e, f), shivering-forward hyperflexion (shivering-FHF; g, h) and stringhalt (i, j).

the stride characteristics could be carried out semi-quantitatively. This included 10 shivering-HE horses, 10 shivering-HF horses, 4 shivering-FHF horses and 9 control horses.

Backward walking: The arc and duration of the swing phase as well as the AUC was similar for control and shivering-HE horses (Fig 4). Horses with shivering-HF, shivering-FHF and stringhalt had pronounced hyperflexion, with a prolonged duration of the swing phase compared with control horses (Fig 4). Shivering-FHF horses (17.7 ± 2.8 cm^2) had a similar AUC to horses with stringhalt (12.2 ± 7.0 cm^2) and a significantly larger AUC than control horses (2.4 ± 0.9 cm^2, P<0.0001), shivering-HE (1.5 ± 0.6 cm^2, P<0.0001) and shivering-HF horses (7.5 ± 3.0 cm^2, P = 0.022). Shivering-HF horses had a greater AUC than control horses and those with shivering-HE. Control horsess and those with shivering-HE had similar AUC during backward walking. Horses with stringhalt had higher AUC than control, shivering-HF and shivering-HE horses.

Forward walking: Shivering-HF, shivering-HE and control horses had a similar arc and duration of the swing phase (Fig 4). Horses with shivering-FHF had the longest duration of swing phase, with an early, progressive ascent to hyperflexion and a rapid descent of the hoof near the end of the swing phase (Fig 4). Horses with stringhalt also had a longer than normal swing phase duration that was characterised by a more rapid ascent to hyperflexion of the hindlimb (Fig 4). Shivering-FHF horses (19.3 ± 4.5 cm^2) had larger AUC than control horses (2.7 ± 0.7 cm^2, P<0.0001), shivering-HE (2.1 ± 0.8 cm^2, P<0.0001) and shivering-HF horses (2.8 ± 1.5 cm^2, P<0.0001) as well as horses with stringhalt (9.2 ± 5.8 cm^2, P<0.0001). The AUC did not differ among control, shivering-HE and shivering-HF horses. Horses with stringhalt had greater AUC than control, shivering-HE and shivering-HF horses.

Discussion

The purpose of the present study was to provide a detailed clinical description of shivering as a means to distinguish shivering from another confounding hindlimb movement disorder, namely stringhalt. Previous literature dating back to the 19th century provides a wide variety of descriptions of abnormal movements for shivering [3,5,7–27]. In one of the earliest articles addressing shivering, the signs were described as 'difficulty in getting a horse to back-up, a raised croup or arched back, rigid hindquarter muscles, and quivering hindlimbs raised from the floor' [26]. In more recent literature, the hallmark signs of shivering are described as marked hyperflexion and abduction of a hindlimb during backing up [1,3,7,8,15,28,29]. The results of the present study indicate that in some cases of shivering, walking backwards is characterised by extensor muscle hypertonicity and great reluctance to move backwards (shivering-HE), whereas other cases show marked flexor muscle hypertonicity when walking backwards (shivering-HF). For shivering-HE, the semi-quantitative video analysis produced nearly identical arcs and AUC during the swing phase compared with the normal horses in forward or backward locomotion, whereas shivering-HF horses had a longer swing phase, higher vertical displacement and AUC and often abduction of the hindlimbs with

Fig 3: Marked abduction and hyperflexion in a shivering-FHF horse during forward walking (a) compared with hyperflexion and lack of abduction in a horse with acquired bilateral stringhalt (b). Hyperflexion was intermittent with shivering-FHF and consistent with stringhalt.

backward walking. Thus, it seems that there are distinct subcategories of shivering with different hindlimb locomotor patterns when walking backwards.

The term shivering arises from the clonic-tonic muscle contractions that occur in the hindlimbs during backward movement [9,26,27,30]. The origin of the muscle hypertonicity is as yet unknown, because neither peripheral nor central nervous system lesions have been found in the limited number of studies available [11,22,23,31]. It is possible that in shivering horses physiological dysfunction occurs within the neurons that regulate walking backwards and, depending on which pool of neurons is primarily affected, excessive hindlimb flexion or extension occurs. Thus, the subcategories of shivering could represent different phases or presentations of the same disease process or alternatively, shivering-HF and shivering-HE could represent different neurological conditions. It is interesting to note that shivering-HE horses also showed extension of their forelimbs when asked to back up and that both shivering-HE and shivering-HF horses were unable to maintain a normal contralateral near-2-beat pattern during backward walking. Thus, shivering may not only represent dysregulation of flexors and extensors within a hindlimb but may also represent dysregulation of backward movement among all 4 limbs. Facial grimacing could also suggest more widespread neurological dysfunction or indicate that the dystonia experienced is painful to the animal.

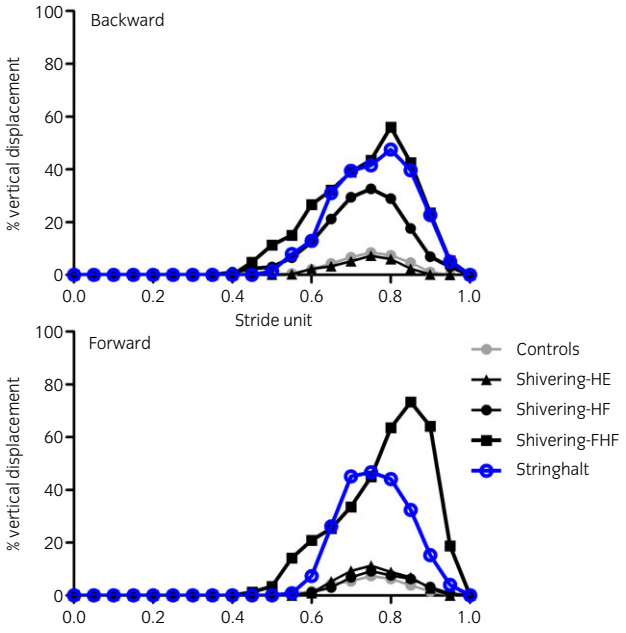

Fig 4: Pattern of the average percentage vertical displacement of the affected (or randomly chosen control) hindlimb over one representative stride unit (from 0 to 1) for a subset of control horses (n = 9) and horses with shivering-HE (n = 10), shivering-HF (n = 10), shivering-FHF (n = 4) and stringhalt (n = 7) walking backwards and forwards. HE = hyperextension; HF = hyperflexion; FHF = forward HF.

While forward walking was normal in both shivering-HF and shivering-HE, some horses showed intermittent hyperflexion abduction and prolonged stride times during forward walking. These horses, classified as shivering-FHF, subjectively seemed to have a period where the limb was fixed in peak hyperflexion and precariously, the opposite hindlimb could start its swing phase when both hindlimbs were in the air. Based on a chronic history of shivering-HF and the large peak in vertical displacement in shivering-FHF horses (both forwards and backwards), these cases of shivering-FHF appear to be a progression of shivering-HF. Dysregulation of flexor and extensor hindlimb muscles within and across limbs could have progressed to a point where not only is backward walking severely impacted but now forward walking is also intermittently impacted, especially during initiation of walking or turning.

Acquired bilateral stringhalt is an important differential diagnosis for shivering-FHF, particularly as they appeared identical in the shape of the swing phase during backward walking. Distinguishing features, however, during forward walking were shorter stride times and abrupt, rapid hyperflexion earlier in the swing phase in horses with stringhalt compared with shivering-FHF horses. Furthermore, during forward walking, horses with stringhalt showed hyperflexion in >77% of the strides recorded and lacked abduction of the limb, whereas abducted hyperflexion was a much more intermittent occurrence (<23% of strides) in shivering-FHF. These findings are in agreement with a kinematic analysis of stringhalt [11]. In contrast to shivering, acquired bilateral stringhalt is often acute in onset and believed to be the result of a peripheral neuropathy following ingestion of *Hypochaeris radicata* [20]. Traumatic injuries to the hindlimb and other peripheral neuropathies can also present as unilateral or bilateral stringhalt [4]. Another reported distinguishing feature between shivering-FHF and

stringhalt is that stringhalt usually persists at a trot, whereas shivering horses have a normal trotting gait [1].

The cases of both shivering-FHF and stringhalt in the present study were quite severe and may not truly reflect the difficulty of trying to establish an early diagnosis of either disorder. Mild cases of acquired bilateral stringhalt may show signs of hindlimb flexion only when walking backwards and during manual lifting of the limbs [6]. Differentiation from shivering in such cases would require information on acute or chronic onset [6], seasonality and geographical location [1,6,32]. Further complicating the picture are draught horses colloquially referred to in North America as 'stringy'. These horses have mild difficulty in backing and intermittent mild abduction and hyperflexion of hindlimbs with forward walking, especially after standing still [33]. Polysaccharide storage myopathy has been suggested to account for some of these cases [11]. Until the aetiopathology of shivering is established, it will be difficult to know if forms of shivering described in the present study and 'stringy' represent a spectrum of one disease or distinct diseases.

The sole sign of hindlimb hyperflexion when the limb is manually lifted was not considered to be pathognomonic for shivering in the present study. Horses were afflicted either unilaterally or bilaterally, and signs could easily have been behavioural in nature or be related to neuropathic or musculoskeletal pain. In discussing cases with owners, signs inconsistently progressed to affect walking backwards. Thus, it is the authors' recommendation that signs of hyperflexion solely apparent with manual lifting of the limb should not be considered diagnostic for shivering and that further diagnostics should be pursued to rule out a musculoskeletal injury. The most difficult cases to assess were those which completely refused to allow their hindfeet to be lifted manually. In the authors' experience, some of these cases progress to show signs of shivering-HE or shivering-HF.

Other differential diagnoses for stringhalt and shivering include fibrotic myopathy and upward fixation of the patella [1,3,34]. However, these 2 musculoskeletal disorders have very characteristic gait patterns; fibrotic myopathy cases exhibit a restricted protraction of the affected hindlimb, leading to an abrupt end of the swing phase during forward walking (backward walking is normal) [1], whereas upward fixation of the patellar cases walk normally (forwards and backwards) but when the patellar becomes locked over the medial trochlear ridge, the stance phase (or if affected the swing phase) will become prolonged until the patellar disengages [1]. Both fibrotic myopathy and patellar fixation cases show normal manual lifting of the hindlimbs.

Although there may well be distinct differences in the height and pattern of hyperflexion in shivering and stringhalt cases, minimal statistical comparisons of vertical displacement of the hoof were made in the present study. This was because there was no way to standardise distances from the camera, camera height or camera angle, all of which impact the accuracy of vertical measurements. Ideally, a standardised kinematic analysis of shivering horses should be performed; however, it would be very difficult to assemble a large number of horses with shivering and stringhalt at a site that has gait-analysis equipment available. The results of the present study serve as general clinical guidelines for the differences in movements between normal horses and shivering and stringhalt cases.

In conclusion, in addition to a complete lameness and neurological evaluation, evaluation of horses for movement disorders should include the following assessments: walking horses forwards and backwards for at least 10 strides; turning sharply; and manual lifting of each limb. As the pathophysiological basis for movement disorders like shivering is unknown, a diagnosis is currently based on clinical signs. Based on the results of this study, the authors suggest that a clinical definition of shivering should include chronic difficulty in backing up, characterised by muscle hypertonicity that results in either excessive hindlimb hyperflexion or excessive hindlimb rigidity and extension. Advanced cases of shivering will, in addition, show intermittent hyperflexion and abduction of the hindlimbs at the initiation of forward walking or when turning. While backward walking is very similar between shivering and stringhalt, the chronicity and intermittency with which forward walking is affected in advanced shivering cases distinguish this disorder from stringhalt. The sole sign of hyperflexion of the hindlimb when it is lifted manually was considered insufficient for a diagnosis of shivering.

Authors' declaration of interests

No competing interests have been declared.

Ethical animal research

The owners of all videoed horses provided informed consent.

Sources of funding

The United States Equestrian Foundation and The University of Minnesota Equine Centre with funds provided by Minnesota Racing Commission graciously provided funds for this project.

Authorship

A.C.E. Draper, S.J. Valberg, T.N. Trumble, I.G. Mayhew, S. Reed and A.M. Firshman contributed equally to the study design, data analysis and interpretation. A.C.E. Draper and S.J. Valberg contributed to the study execution and manuscript preparation equally. J.D. Baird, T.N. Trumble and R. MacKay provided additional video contributions, and contributed equally with S. Reed, I.G. Mayhew, A.C.E. Draper, S.J. Valberg and A.M. Firshman to final manuscript approval.

Manufacturers' addresses

[a]Apple, Cupertino, California, USA.
[b]Geometric Constructions, Stanford, Conneticut, USA.

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Video S1: Standing HF.
Video S2: Shivers-HE.mov.
Video S3: Shivers-HF.mov.
Video S4: Shivers-FHF.mov.
Video S5: Stringhalt.