Effect of ground and raised poles on kinematics of the walk

Walker, V A; Tranquillle, C A; MacKechnie-Guire, R; Spear, J; Newton, R; Murray, R C

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VA Walker*[1], CA Tranquillle[1], R MacKechnie-Guire[2], J Spear[1], R Newton[1], RC Murray[1].

[1]Animal Health Trust, Lanwades Park, Newmarket, Suffolk CB8 7UU, UK ; [2]Centaur Biomechanics, Dunstaffanage House, Moreton Morrell, Warwickshire, CV35 9BB, UK.

Current addresses: Walker and Tranquille: Hartpury University, Hartpury, Gloucestershire, GL19 3BE, UK; Spear: Calico Cottage, Norwich, Norfolk, NR15 1UG, UK; Newton: Cambridge Veterinary School, Madingley Road, Cambridge, Cambridgeshire CB3 0ES, UK; Murray: Rossdales Ltd, Cotton End Road, Newmarket, CB8 7NN, UK.

*Corresponding author: victoria.walker@hartpury.ac.uk

Authorship

VW, CT, JS, RMG and RM contributed to the experimental design, data collection, analysis and writing up of this project. RN was responsible for statistical analysis and writing up.

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Competing Interests

None to declare

Ethical animal research

This project was ethically approved by the Animal Health Trust Ethical Committee Project Number: 52-2015.

Informed consent

Informed consent was received from all horse owners prior to data collection.

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Highlights

Walking over poles increases fore and hindlimb joint range of motion (ROM)
Walking over ground and raised poles increases fore and hindlimb swing phase flexion
Walking over raised poles has a greater impact on limb ROM than ground poles
Walking over poles does not change vertical excursion of the poll, wither and sacrum
Walking over poles increases mediolateral ROM of the withers and pelvis

Abstract

Walking over poles is a commonly employed training and rehabilitation tool and it is crucial to understand its effect on equine locomotion, particularly joint range of motion (ROM). The aim of the study was to compare the effect of ground poles (GP) and raised poles (RP) on limb kinematics and poll, wither and pelvic ROM at walk. It was hypothesised that walking over poles would increase joint ROM but have no effect on poll, wither and pelvic ROM compared to no poles (NP). Forty-one horses were walked in-hand over NP, GP (10cm high) and RP (26cm high) in a crossover design. Limb kinematics were determined via two-dimensional motion capture at 240Hz and poll, wither, tubera sacrale, and left and right tuber coxae craniocaudal, mediolateral and dorsoventral ROM were determined by inertial motion units (IMUs) at 100Hz. Multivariable mixed effects linear regression analyses were carried out. Walking over poles increased limb joint ROM, through increased swing flexion, compared to NP. There was a greater effect over RP compared to GP. Significant reductions in craniocaudal ROM of the wither, tuber coxae and tuber sacrale were observed over GP and RP. Increased poll craniocaudal ROM was seen over RP compared to NP only. Mediolateral ROM of tuber coxae and tuber sacrale increased over GP and RP and was greatest over RP. Wither ROM was increased over RP only. Dorsoventral right tubera coxae ROM decreased over RP compared to NP only. Set-up and height of the poles used here may not extrapolate to other scenarios. Walking over poles appears to be effective at increasing joint ROM via an increase in mid swing flexion, without vertical excursion of the trunk, compared to normal locomotion. Given that this is a key early rehabilitation goal for many horses it supports the use of poles for this purpose.

1. Introduction

There is increasing recognition of the importance of rehabilitation in management of orthopaedic conditions in horses, but there is limited description of the biomechanics of exercises which may be used as part of a rehabilitation programme. Exercise methods that have been investigated, in terms of biomechanical and muscle activation and strengthening, include dynamic mobilisation exercises [1-3], water treadmills (WT) [4-6], training aids [7,8] and trotting over ground (GP) and raised poles (RP) [9,10]. It is proposed that polework provides a mechanism for all the rehabilitation priorities once pain has been resolved [9-12]; establishing or restoring ‘optimal’ movement patterns [13], addressing proprioceptive deficits, stiffness, weakness or fatigue and improving neuromuscular control [14]. Raised poles as part of a 4-week gymnastic training programme resulted in an increase in cross sectional area of the multifidus [15] and comparisons of surface electromyography (sEMG) over ground poles at the walk demonstrated largely bilateral peaks for rectus abdominis activity compared to over ground walking [16]. This has also been observed at the trot over GP and RP [17]. However, the kinematics of walking over poles on the kinematics of the limb and trunk has not previously been investigated

Controlled exercise is the foundation of any rehabilitation programme [18] and controlled in-hand walking is the most frequently employed intervention based on a recent questionnaire of current practice worldwide [19]. Initial rehabilitation for many orthopaedic conditions is largely limited to walk, with subsequent progression to trot [20]. Trotting over poles in straight lines increased limb and joint flexion [10] without an increase in ground reaction forces [9] suggesting that poles may be a useful tool to achieve a key rehabilitation goal of increasing limb range of motion (ROM) [12, 14] without risking overloading limb structures which may still be recovering from injury [9]. Walk and trot are both symmetrical gaits with similar joint motion patterns and swing durations but have differences in interlimb coordination patterns [21]. Walk has no moment of suspension and lower groud reaction forces which make it the more suitable gait for early stages of rehabilitation. Further knowledge of the effect that polework has on the joints of the limb at the walk can improve our growing evidence base for more appropriate selection of exercise-based interventions in rehabilitation programmes.

Pole work exercise has also been advocated for developing dynamic stability in the horse as the requirement of the horse to lift one diagonal pair whilst stabilising with the other without raising the relative height or position of the trunk. This is useful for both training and rehabilitation due its ability to enhance proprioceptive skill, balance and muscle strengthening [9,10]. Understanding how trunk and limb kinematics are influenced by GP and RP is relevant for practioners when deciding which pole height to select in practice.

It was predicted that the effect of poles on walk kinematics would be similar to those observed in the trot and that the horse would clear the poles through changes in joint flexion of the limbs in flight and that this would not increase mid-stance kinematics. There would be no influence on the movement of the relevant height or position of the trunk of the horse as determined by inertial motion units (IMU) [9,10].

We therefore hypothesised that walking over poles would: 1. increase joint ROM in all fore and hindlimb joints through increase in swing phase angles over poles compared to no poles (NP); 2. There was be a significantly greater effect over RP compared to GP; 3. There would be no significant differences in ROM of the poll, withers, tubera sacrale, left and right tuber coxae based on IMU data over poles compared to NP. There would be no significant differences between RP compared to GP.

2. Materials & Methods

2.1 Animals

Forty-one horses (mean±S.D., age 9±5years; wither height 148±12cm; eight cobs, six warmbloods, seven Thoroughbreds and 20 native ponies) underwent lameness assessment by a veterinary specialist clinician and deemed clinically sound. Level of training and exercise of all horses was recorded. All horses were experienced at walking over poles.

2.2 Measuring systems

Thirty-six hemispherical markers were placed at predetermined anatomical sites on the left and right sides of each horse (Figure 1) by a single experienced researcher according to palpable surface landmarks [22].

Horses wore five MTw IMUs (Xsens[a]) using a validated sensor-based system [23,24]. These were attached over the poll, withers, tubera sacrale, and left and right tubera coxae, using custom built pouches and double-sided tape with the horse standing square. The same researcher applied sensors throughout the study. To reduce variability, sensors remained on the horse throughout the entire data collection. In brief, tri-axial sensor acceleration data were rotated into a gravity (z: vertical) and horse-based (x: craniocaudal and y: mediolateral) reference frame and double integrated to displacement. Displacement data were segmented into individual strides based on vertical velocity of the tubera sacrale sensor [25] and median values for kinematic variables were calculated over all strides for each exercise condition.

2.3 Study Protocol

Weighted plastic poles, 3m long and 10cm in cross section were used. Three adjacent lanes were set-up in the middle of a waxed sand and fibre surface arena; one lane with NP, one lane with five ground poles (GP) (10cm high) spaced 75±5cm apart and one lane with five RP (26cm high) spaced 70±5 cm apart. Each test lane was 10m wide and 20m long (Figure 2) and marked out with cones.

Horses were walked in-hand for five minutes around the test area for acclimatisation and warm up. For the test, horses were walked in a straight line four times, twice on each rein, down the middle of each test lane being led from both sides to ensure straightness. High-speed motion-capture was obtained from both sides simultaneously. Horses walked at their own comfortable pace. Half of the horses started with NP and the other half started over RP; GP was always the second test condition.

2.4 Data collection

Limb kinematics were quantified using two-dimensional high-speed videography (Casio[b]). Data was collected from the left and right sides at 240Hz using a 5m field of view.

The IMUs collected triaxial sensor data calculating the displacement of the sensors in the dorsoventral, craniocaudal and mediolateral planes of all five units. Sensor data were collected at 100Hz per individual sensor channel and transmitted via proprietary wireless data transmission protocol (Xsens[a]), to a receiver station (Awinda[c], Xsens) connected to a laptop computer running MTManager (Xsens[a]) software. The IMUs used had an internal sampling rate 1000Hz, a buffer time 30seconds and their dimensions are 47x30x13mm and mass 16grams. Their dynamic accuracy is 0.75degrees root mean square (RMS) (roll/pitch) and 1.5degrees RMS (heading).

2.5 Data Analysis

Shoulder angle was measured using markers 1, 2 and 3; elbow angle was measured using markers 2, 3 and 4; carpal angle was measured using markers 3, 4 and 5; metacarpophalangeal joint angle was measured using markers 5, 6 and 7; hip angle was measured using the IMU that was placed on the tuber coxae and markers 14 and 13; stifle angle was measured using markers 14, 13 and 12; tarsal angle was measured using markers 12, 11 and 10; metatarsophalangeal joint angle was measured using markers 10, 9 and 8 (Figure 1). Shoulder, elbow, carpal and metacarpophalangeal joint angles were measured on the caudal/palmar aspect of the limb, hip and tarsal angles was measured on the cranial aspect of the limb and stifle and metatarsophalangeal joint angles were measured on the caudal/plantar aspect of the limb. Joint angles were measured at mid-stance (when the third metacarpus/metatarsus were vertical) and at mid-swing (when the carpus/tarsus joint was maximally flexed). Video analysis was conducted using digital image analysis software (Pro Analyst Professional edition, Xcitex[d]). Stride length, stride and stance duration were calculated from hoof surface impact and toe lift off [26, 27]. From these speed, swing duration, occurrence of mid-stance and mid-swing as a percentage of the stride were calculated.

Repeatability of marker tracking was determined by tracking all markers and deriving angles five times in three horses. A coefficient of variance of <3% was calculated and deemed acceptable based on previous studies [24, 25].

IMU data were used from 5±1 repeated walk strides, per repeat/condition each was used for the analysis. Outcome parameters were ROM in a dorsoventral, craniocaudal and mediolateral direction for the five sensors.

2.6 Statistical Analysis

Descriptive statistics were carried out for each variable at each condition using statistical analysis software (Analyse-It for Excel Microsoft version 1.73). Univariable mixed effects linear and polynomial (quadratic terms) regression analyses were used to examine the relationship between outcome variables and each predictor variable separately, with horse identity used as a random effect term in order to control for the multiple (‘clustered’) measures that were taken from each horse (using Stata 15.0). A significance value of $P \leq 0.05$ was applied in all analyses.

3. Results

3.1 Limb kinematics (Tables 1)

3.1.1 Forelimb

3.1.1.1 Absolute joint angles

At mid-swing there was a significant decrease in elbow and carpal angle from NP to GP to RP ($P \leq 0.0001$ for all). Metacarpophalangeal joint angle was significantly decreased between NP and GP and RP, but no significant chanes were seen between GP and RP ($P=0.172$). Mid-swing shoulder angle was not significantly different between NP and GP but there was a significant decrease in mid-swing shoulder angle over RP compared to GP ($P=0.04$) and NP ($P=0.003$). No significant differences were observed in any of these angles at midstance between NP, GP or RP ($P \geq 0.05$).

Comparing within-stride temporal variables between pole types showed a significant increase in forelimb swing duration over RP compared to NP and GP ($P \leq 0.0001$ for both), no signifncant differences were observed between NP and GP ($P=0.340$). Forelimb mid-stance occurred earlier in the stride over RP compared to NP ($P \leq 0.0001$) and GP ($P=0.0003$). No significant differences were observed between GP and NP ($P=0.054$).

3.1.1.2 Range of Motion

There was a significant increase in ROM of the elbow, carpus and metacarpophalangeal joint over GP and RP compared to NP ($P \leq 0.0001$ for all). No significant differences were seen for shoulder ROM ($P=0.277$, 0.132, 0.743 for NP vs GP, NP vs RP, GP vs RP respectively). These changes increased significantly from GP to RP for all angles ($P \leq 0.0001$ for all), except metacarpophalangeal joint ($P=0.776$).

3.1.2 Hindlimb

3.1.2.1 Absolute joint angles

At mid-swing there was a significant decrease in hip, stifle, tarsus and metatarsophalangeal joint angle from NP to GP to RP (Hip = NP vs GP $P=0.0015$, GP vs RP $P=0.0150$, $P \leq 0.0001$ for all). No significant differences were observed in any of these angles at mid-stance between NP, GP or RP ($P \geq 0.05$).

For within-stride temporal variables, there was a significant increase in hindlimb swing duration over RP compared to NP and GP ($P \leq 0.0001$ for both). Hindlimb mid-stance occurred earlier in the stride over RP compared to NP ($P=0.0004$) and between GP and RP ($P=0.021$). No significant differences were observed between GP and NP ($P=0.398$ and 0.183 respectively).

3.1.2.2 Range of motion

There was a significant increase in ROM of the hip, stifle, tarsus and metatarsophalangeal joint over GP and RP compared to NP ($P \leq 0.0001$). These changes increased significantly from GP to RP for all angles ($P \leq 0.0001$), except the hip ($P=0.3330$) The largest percentage changes were observed at the level of the elbow and stifle, and the least percentage change were observed in shoulder and the hip.

3.2 Temporal and linear variables

Speed significantly decreased from NP to GP to RP ($P \leq 0.0001$). Stride duration significantly increased from NP to GP to RP ($P \leq 0.0001$). There was also a significant decrease in stride length over poles (GP and RP) versus NP ($P \leq 0.0001$) but no significant differences were observed between GP and RP.

3.3 Horse related variables

Horse related variables such as workload and age had no significant relationship with any of the limb kinematic variables measured ($P>0.05$).

3.4 Inertial measurement units (Tables 2)

3.4.1 Craniocaudal

There was a significant decrease in craniocaudal ROM of the withers ($P=0.0001$), tubera sacrale and left and right tuber coxae over GP compared to NP ($P \leq 0.0001$ for all). Over RP there was a significant decrease in craniocaudal ROM of the withers, tubera sacrale and left and right tuber coxae compared to NP ($P \leq 0.001$) and a significant decrease compared to GP for left and right tuber coxae only ($P=0.043$ and <0.0001 respectively), but an increase in poll ROM compared to over NP and GP ($P \leq 0.0001$ for all).

3.4.2 Mediolateral

There was also an increase in mediolateral ROM of the tubera sacrale and left and right tubera coxae over GP compared to NP ($P=0.0008$ and <0.0001 for both). Over RP there was an increase in mediolateral ROM of the poll, withers, tubera sacrale and left and right tubera coxae compared to NP and GP ($P \leq 0.0001$ for all).

3.4.3 Dorsoventral

No significant differences in dorsoventral ROM for any region were observed between GP and NP ($P \geq 0.05$). There was a significant decrease in dorsoventral ROM of the right tubera coxae over RP vs NP but no significant changes in dorsoventral ROM of any other region were observed ($P \geq 0.05$).There was a significant increase in dorsoventral ROM of wither over RP vs GP ($P < 0.0001$).

4. Discussion

The results of this study supported our first hypothesis as the addition of poles did increase limb joint ROM, through increased swing flexion, compared to NP. Contrary to the second hypothesis there were significant reductions in craniocaudal ROM of the wither, tuber coxae and tuber sacrale over poles compared to NP and an increase in poll ROM over RP compared to NP only. Mediolateral motion of the tuber coxae and tuber sacrale increased over GP compared to NP and this was accompanied by an increase in wither ROM over RP. Dorsoventral ROM was decreased at the right tubera coxa over RP compared to NP only.

The findings of this study support those observed in horses trotting over poles [9,10], suggesting that polework is effective at increasing joint ROM of the limbs without any increases in vertical ROM of the trunk. In this study increases in limb joint ROM occurred via increased flexion during the swing phase of the stride and this was evident over GP and to a greater extent over RP compared to NP. No changes in dorsoventral ROM is a desirable outcome. An increase in dorsoventral displacement may be considered a compensation or a mechanism to limit limb flexion and given that increasing joint ROM is a key rehabilitation goal [12,14], especially in horses which have had a prolonged period off work due to injury and/or after immobilisation our findings support the use of walking poles for this purpose in practice.

One difference was observed at walk compared to trot. Brown et al., (2014) [10] observed an increase in shoulder ROM over ground and RP at trot, but in this study mid-swing shoulder angle was not changed over GP compared to NP but was more flexed over RP. Evaluation of walk and trot over the same pole set up is required for a direct comparison but this difference is useful to note if the goal is to increase ROM of the shoulder as this only occurred over RP at the walk.

Tactile stimulation [27-29] and limb weighting have been shown to increase limb joint ROM [27, 29-31]. To assess the value of rehabilitation interventions as strengthening tools it is crucial to consider the positive power joints which do the concentric work throughout the stride [29]. In the forelimb the elbow drives protraction and retraction in walk and trot [32]. Two studies assessing the impact on weighting of the forelimb with 700g shoes [30] or a 716g bell boot [31] found no significant changes in elbow ROM. In the current study we observed an increase in elbow ROM via increased mid-swing flexion over GP and to a greater extent over RP. This suggests that the musculature which initiates elbow flexion and forelimb protraction, will be strengthened by the necessity to raise the hoof higher and increase limb flexion over the poles. Raised poles induced greater increases in shoulder, elbow and carpal ROM compared to GP, and both appear to be more effective than weighting the limb, both of which are relevant for clinical application. The use of the WT has been investigated to demonstrate increases in the ROM of some distal forelimb joints [5] but there is limited evaluation of elbow ROM in the WT probably due to visibility of the proximal joints.

Tactile stimulation [27, 29] and weighting of the hind pastern [28] was observed to increase hindlimb ROM by stifle and tarsal flexion but there was no change in hip flexion angle. This suggests that they may be useful for strengthening the tarsal and stifle musculature, including that of the reciprocal apparatus[29] which are responsible for lifting the hindlimb [27]. They are not likely to influence hindlimb protraction [32, 33] as neither intervention increased hip flexion [27, 29]. Another factor to consider with these interventions was that the effect did decrease over time and the horse habituated to the stimulation of the cutaneous mechanoreceptors of the pastern or to the additional weight [27-29]. Prolonged, albeit smaller, changes in ROM were seen in one study [31] so it may have some potential benefits for the distal joints and the use of an intermittent bell boot on one hindlimb was also seen to increase hindlimb muscle symmetry in asymmetrical horses when used for six weeks [34] but this study used acoustic myography to measure muscle function as opposed to kinematics which makes direct comparison difficult. In the current study we observed an increase in a hip ROM, through an increase in maximal flexion during swing, and this increase was greatest over RP but also seen over GP compared to NP. This suggests that both GP and RP may be useful tools for increasing activation and strengthening of the hip, stifle and tarsal musculature as well as potentially increasing hindlimb protraction [32], but this effect is greatest over RP. When considering exercise selection it is important to note these effects are only present as the horse goes over the pole, therefore the number of repititions that the horse performs during a session will impact the intensity of this stimulus. On the other hand there appears to be no diminishing effect as the horse completes the repititions, although further work is required to confirm this as we did not measure this directly in the current study. The ability of the handler to amend these stimulus within and between sessions is valuable in a clinical scenario to provide progression and regression of the exercise as required [35].

The use of the WT to increase joint ROM has been identified and there appears to be an influence of water depth of the ROM of individual joints [5]. There are some considerations regarding the influence of the drag created by the water that may influence forelimb protraction and hindlimb retraction [36] and apparent individual variation on hindlimb protraction ROM based on water depth in the study population of Nankervis and Lefrancois [36]. To date there is no data on hip ROM on a WT so no comments can be made based on its ability to strengthen the hip musculature but the increase in ROM of the more distal joints supports its use for strengthening the tarsal musculature [5, 36]. It is interesting to note that whilst the addition of poles appears to increase ROM of the proximal joints, such as the elbow and hip, they also result in a greater increase in distal limb joint ROM, particularly the tarsus compared to the WT. For example, GP resulted in an increase in tarsal flexion of 36° and RP 62°, this is compared to the WT which resulted in an increase of 20° in tarsal depth water [5]. These were different populations but this suggests that poles may be preferable for increasing overall tarsal ROM and subsequently strengthening the tarsal musculature through the full ROM. However, it is important to note though that whilst this may be useful in the early stages as the horse gets stronger and adapts there will be a need to provide more of a stimulus for further adaptation and then the treadmill may be become a more efficient way of doing this if increasing tarsal flexion is the goal. For example, during a 15 minute session with the horse walking at 40 strides per minute the horse will complete 600 strides or 600 increased flexions of the tarsus [37]. For context, this would be 120 sets over five poles, which is considerably more than is commonly used in a single session. It is important to highlight that the ROM of the limb is also influenced by the surface selected, and differences between land treadmill, hard and soft surfaces have been observed in sound horses with differences seen between different distal limb joints [38]. This is a relevant factor to consider when considering the effects of different modalities and different distal limb joints.

The effect of poles is not only to change limb ROM; they also facilitate visuomotor, neuromotor and proprioceptive development as well as coordination [12]. The horse is required to lift legs and process its own placement relative to the poles and also coordinate this with several poles in sequence. The use of this in the walk provides a slower speed and a more stable base for the horse, given there is always two limbs in contact with the ground, to learn and develop this process before progressing to the trot where the time to carry this out is reduced [9,10]. The temporal variables at walk were similar to the findings reported at trot [9,10], there was an increase in stride duration over poles and an increase in swing duration of the fore and hindlimbs. This change in stride duration was also observed by Clayton et al. [9] in horses with different types of tactile stimulators around the hind pasterns and by Mendez-Angulo et al. (2013) [5] at walk on the WT. The consistency of this observation in horses which have increased mid-swing flexion may suggest that increasing stride duration is required to facilitate this change in limb kinematics and would be an interesting area for further study.

The addition of poles resulted in a decrease in speed, as it did for Brown et al., (2014) [10]. This was explained as an aspect of task completion and our findings suggest the horse does need to reduce its speed to successfully negotiate the poles. We observed an increase in stride length between conditions, which was not seen by Brown et al. (2014) [10] in trot. This could reflect the set-up used in this study and reflect the distances between the poles. These were set based on horse height but this does not take into account relevant limb length or the horse's 'natural gait'. Further work is required to ascertain 'optimal' distances and how these are affected by individual horse characteristics.

In terms of other differences in trunk motion observed via the IMUs there were some interesting patterns. With the addition of poles, we observed a decrease in craniocaudal ROM which is likely to be due to the horse's reduction in speed to facilitate negotiation of the poles, compared to its 'normal' walking pace. This was also seen over RP but it appears that over this set-up the horse may use its neck to balance [39], as seen by the increase in the craniocaudal ROM at the poll only. The addition of the poles provided a clear pattern in terms of mediolateral motion of the horse. The mediolateral ROM increase over poles is likely due to the need of the horse to stabilise on one hindlimb whilst elevated the other which may result an increase in mediolateral ROM of the pelvic region over the poles compared to over ground and the addition of the increased mediolateral ROM in the wither over RP may indicate this is required as part of the stabilisation for elevation of the forelimbs over RP. There is some scope for discussion as to whether this is a desirable outcome or is in fact a compensation for horses who are unable to stabilise appropriately with the grounded limbs. It is important to highlight that this is another factor which challenges the horse during polework as it must find its balance and be strong enough to stabilise through the weight-bearing limb and its associated musculature to be able to move the swing phase limb [12]. The approaches adopted here would be useful to investigate in more detail with a three-dimensional motion capture system which would enable evaluation of the whole horse simultaneously.

The only observation which indicated a change in the dorsoventral ROM was in the right tuber coxae over RP and this may be due to handler effect or established movement patterns due to commonly being worked with a left side handler only given each horse had two a handler per side. Shaw et al. (2021) [16] observed an increase in sEMG of the longissimus dorsi across the stride over GP compared to NP on the right side only so it may be that handedness preference was quantified in this and the current study. Further work would be useful to investigate this.

A significant area of interest when a horse is working over poles is to review their ability to step over the poles without compensatory roll of the body. This presence of such compensations would indicate that the horse is unable to produce the required elevation purely by limb flexion and is having to use rotation around the longitudinal axes in order to clear the poles. The results observed here indicate that in this study sample the horses were able to clear the poles without this vertical compensation but it is possible that a horse which is having to rotate or deviate considerably side-to-side is not ready for the height of pole used or may not be dynamically stable enough to respond appropriately to polework at this stage of their training or rehabilitation. Currently there is no objective measure which indicates a threshold for mediolateral movement and what is required to execute the task and what may be considered an indicator of insufficient dynamic stability for task completion. The presence or absence of compensatory roll could be an important method of monitoring the exercise, which could be evaluated by a handler, but the production of objective values would be useful to ascertain in future work.

There appears to be an effect of pole set up (GP vs RP) in terms of ROM and balance requirements for the horse, with RP inducing a greater increases and challenges for both. It is vital that the model of progression, as mentioned earlier is followed in that the horse must be able to successfully and correctly negotiate the GP before the additional challenge of the RP [12, 40]. It is crucial that the horse has developed the strength and capacity for protraction and limb flexion for the GP before considering moving onto the RP. It is imperative that the handler is evaluating the horse continuously throughout the session for undesirable movement patterns, compensations and fatigue and that pole set-up and repetitions carried out are progressed in the context of the horse's capabilities.

It appears that poles are effective for attaining many of the key rehabilitation goals outlined by practitioners such as increasing limb ROM, strengthening key musculature, facilitating visuo and neuromotor development, balance and coordination [12-14, 20]. The effect of poles for core muscle activation have already been established [16, 17, 40] but the findings the current study suggest poles may be indicated for strengthening the limb protractors and the tarsal flexors at the walk. These findings add to the growing evidence base regarding exercise interventions for the rehabilitation of the horse and provide clinically relevant observations which practitioners can use to inform their exercise selection for individual cases.

4.1 Limitations

Two-dimensional motion capture was used to calculate limb angles, and this means any rotation of the joints will not have been considered. The handlers were used on both sides of the horse to try and limit handler effect, but some horses did tend to respond more to the left handler as they were in the conventional position for leading the horse. All the horses in the study were accustomed to working over poles so the findings observed here may not be replicated in a naïve population. One of the key factors which is crucial readers are aware of is the set-up and height of the poles used in this study, which were set based on physiotherapist guidance, but this is a subjective assessment which may vary amongst individual professionals. The pole height was consistent across the whole sample for standardisation purposes. However, in practice, pole height may be altered based on horse height.

4.2 Conclusions

The findings of this study suggest that the use of walking poles is effective at increasing joint ROM via an increase in mid-swing flexion, without vertical excursion of the trunk, compared to normal locomotion. Given that this is a key early rehabilitation goal for many horses it supports the use of poles for this purpose. The greater flexion of the elbow, hip and tarsus suggests that walking over poles may help to develop the associated musculature of these joints which is likely to have positive impacts for strengthening in both rehabilitation and training. It appears that the effects of walking over RP induces the same effects but to a greater degree than GP so it is vital that the horse has the appropriate strength and coordination for progression to RP and emphasises the role of the handler to ensure that the horse is working with optimal movement patterns for any set-up used.

Manufacturers' Addresses

[a]Xsens, Enschede, The Netherlands
[b]Casio, Priestly Way, London
[c]Awinda. Xsens, Enshede, The Netherlands
[d]Xcitex, Pro Analyst, Cambridge, MA, USA

Tables

Variable		***Condition***		
		NP mean±sd	**GP**	**RP**
MCPJ (°)	Mid-swing angle	182.1±11.2*	159.5±11.0^	157.6±10.4
	ROM	46.9±9.8*	65.4±9.2^	64.5±7.6
Carpus (°)	Mid-swing angle	136.1±6.2*	118.0±9.6^	102.9±10.4×
	ROM	42.3±5.7*	59.8±8.0^	74.6±9.3×
Elbow (°)	Mid-swing angle	248.2±7.1*	268.7±7.3^	274.9±8.2×
	ROM	31.8±5.1*	53.1±5.9^	58.0±6.4×
Shoulder (°)	Mid-swing angle	119.6±8.6	118.8±10.2	116.3±10.8
	ROM	3.2±1.6	3.5±1.5^	3.8±1.4×
MTPJ (°)	Mid-swing angle	175.4±7.8*	151.1±10.0^	144.4±10.1
	ROM	41.9±7.8*	65.5±8.7^	72.7±8.4×
Tarsus (°)	Mid-swing angle	117.9±9.3*	81.7±9.6^	53.3±12.3
	ROM	40.0±6.6*	75.9±8.3^	102.8±12.0×
Stifle (°)	Mid-swing angle	118.3±12.0*	107.6±10.9^	100.3±11.0
	ROM	9.7±5.0*	19.4±6.7^	27.0±8.3×
Hip (°)	Mid-swing angle	68.0±6.7*	66.8±5.6^	66.0±5.5×
	ROM	8.1±2.5	9.2±2.7^	9.8±2.8×
Stance duration (%)	FL	66	66^	65×
	HL	66	66^	65×
Swing duration (%)	FL	34	34^	35×
	HL	34	34^	35×
Mid-stance (% of stride)	FL	27	26^	25×
	HL	37	36^	35×
Mid-swing (% of stride)	FL	77*	81^	81
	HL	83*	85	85
Speed (m/s)		1.68±0.1*	1.58±0.1^	1.50±.02×
Stride duration (secs)		1.21±0.01*	1.36±0.01^	1.46±0.01×
Stride length (m)		1.2±0.11*	1.30±0.09^	1.31±0.11

Table 1. Mean and standard deviation for all data pooled for limb joint angles at mid-swing, limb joint angle range of motion (ROM), stance and swing duration, speed, stride duration and length in 41 horses that walked over ground, over ground poles and over raised poles. MCPJ = metacarpophalangeal joint; MTPJ = metatarsophalangeal joint; ° = degrees; FL = forelimb, HL= hindlimb; NP = no poles; GP = ground poles; RP = raised poles *= significant difference between no poles and ground poles, ^= indicates significant difference between raised poles and no poles, × = indicates significant difference between ground poles and raised poles..

Variable (mm)		**NP**	**GP**	**RP**
		mean±sd		
Poll	**Dorsoventral**	105.4±29.0	102.4±32.1^	106.2±33.6
	Mediolateral	59.5±19.1	61.7±20.0^	77.3±24.6◦
	Craniocaudal	73.5±26.4	72.0±25.7^	89.1±28.1◦
Withers	**Dorsoventral**	37.7±8.7	34.6±7.8	38.3±8.8◦
	Mediolateral	46.1±12.9	45.3±11.5^	55.8±15.7◦
	Craniocaudal	39.7±9.2*	36.1±10.2^	35.4±7.5
Tubera sacrale	**Dorsoventral**	66.2±11.5	63.8±10.5	65.0±11.0
	Mediolateral	50.5±11.6*	54.2±11.9^	66.2±15.0◦
	Craniocaudal	45.8±10.2*	40.1±8.4^	39.2±8.6
LTC	**Dorsoventral**	90.2±11.7	90.1±14.9	90.7±16.8
	Mediolateral	43.9±9.9*	48.3±10.3^	56.3±12.9◦
	Craniocaudal	53.0±12.4*	48.3±10.1^	46.8±9.9◦
RTC	**Dorsoventral**	91.8±14.5	89.8±15.8^	87.7±14.5
	Mediolateral	43.2±8.2*	47.9±8.9^	58.1±12.5◦
	Craniocaudal	55.8±13.6*	49.8±11.8^	46.3±9.7◦

Table 2. Mean and standard deviation for dorsoventral, mediolateral and craniocaudal ROM for poll, wither, tubera sacrale, left and right tubera coxa inertial measurement units in 41 horses that walked over ground, over ground poles and over raised poles. LTC= left tubera coxa; RTC = right tubera coxa; NP = no poles; GP = ground poles; RP = raised poles, *= significant difference between no poles and ground poles, ^= indicates significant difference between raised poles and no poles, × = indicates significant difference between ground poles and raised poles.

Figure Legends

Figure 1. Marker placement for data collection. (1) proximal aspect of the scapular spine (2) cranial eminence of the greater tubercle of the humerus (3) lateral epicondyle of the humerus over the lateral collateral ligament of the elbow (4) lateral styloid process of the radius (5) proximal aspect of the third metacarpal bone at the junction with the base of the 4th metacarpal bone (6) distal aspect of the third metacarpal bone over the lateral collateral ligament of the metacarpophalangeal joint (7) lateral collateral ligament of the distal interphalangeal joint (designated coronary band) (8) lateral collateral ligament of the distal interphalangeal joint (designated coronary band) (9) distal aspect of the third metatarsal bone over the collateral ligament of the metatarsophalangeal joint (10) proximal aspect of the third metatarsal bone at the junction with the base of the 4th metatarsal bone (11) mid talus (12) proximal aspect of fibula (13) medial epicondyle of the distal femur (14) proximal aspect of the greater trochanter of the femur

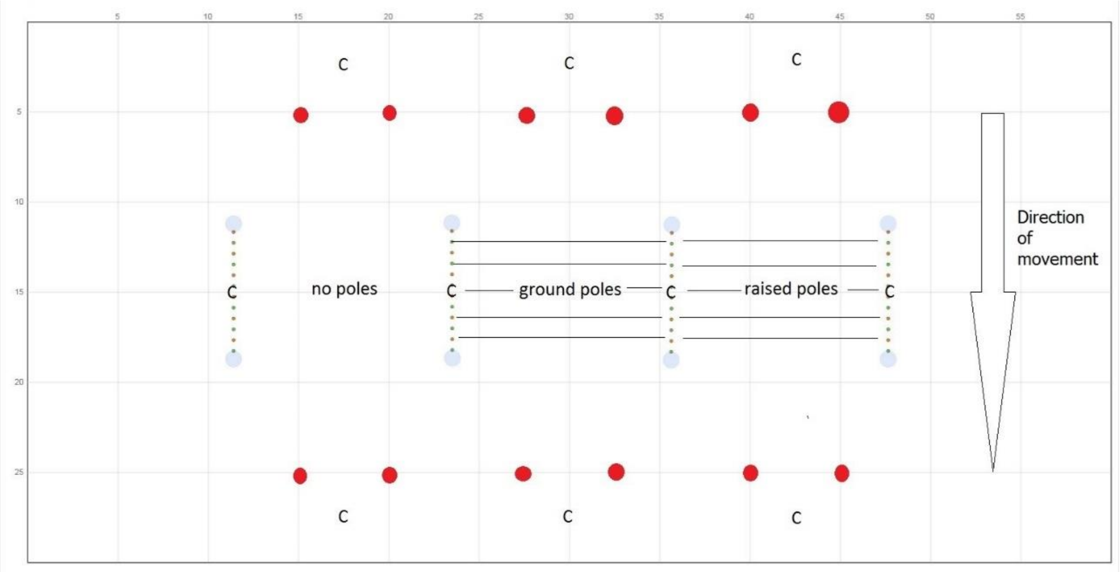

Figure 2: Arena set-up showing three adjacent lanes in a 60 m by 30 m arena. C = camera. Red circles indicate cones which marked out tracks

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