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A narrative review of practical recommendations regarding the impact of negative plantar angle on the longevity of sport horses

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ABSTRACT

The significance of hoof balance in preventing lameness in the distal limb is wellknown and widely described. This review provides an overview of the consequences of inappropriate phalangeal alignment and the improper orientation of the plantar surface of the coffin bone in the hind limb. Today's equine athletes work very close to the limits of the capability of some structures, and any deviations from the perfect conformation can contribute to the breakdown of these structures. Therefore, recognizing and managing a negative plantar angle is essential for the longevity and welfare of a horse's career. A comprehensive summary of this topic emphasizes how this issue affects rideability and health in sport horses. It also discusses future perspectives for developing new methods to study this problem. Monitoring hoof and posture morphology is essential for a proactive approach to horse welfare and soundness. Considering the increasing importance of injury prevention, we should cultivate interest in developing prehabilitation programs for horses with hind hooves imbalances.

1. Introduction

The importance of the hoof balance as the main factor in preventing lameness in the distal limb is well-known and widely described. The textbooks from over 100 years ago described the negative impact of improper trimming and shoeing on foot health [1]. Since then, many studies have further investigated the effects of trimming and shoeing, but the main focus has been on the forelimbs rather than on the hind feet [2]. Even recently, during the pre-purchase examination, X-rays were only taken of the hooves of the front limbs, using a block to assess the sole depth, palmar angle, and digital breakover, whereas those parameters for hind hooves were left overlooked [3]. One of the most common imbalances occurring within the hoof capsule of both the forelimbs and the hindlimbs is the negative plantar angle (NPA). It has been described that for optimal foot conformation, the angle between the solar surface of the coffin bone and the ground surface should be 2–10 degrees [4]. When the tip of the pedal bone tilts upwards, and its palmar processes move downwards towards the ground surface, it is known as a negative palmar/plantar angle. This condition is commonly widespread within the ridden horse population and, together with low heels and the broken hoof pastern axis, is currently considered as an important reason for numerous pathologies [5]. Recognizing abnormal conformation of the hooves is crucial for maintaining their proper shape and function. Based on numerous studies concerning the influence of a negative palmar angle on the structures within the hoof capsule of the front limbs, attention has slowly moved to the evaluation of the coffin bone orientation in the hind hooves [6–9]. As front limbs are responsible for weight bearing and hindlimbs are engaged in propulsion, different consequences are expected due to the occurrence of a negative palmar/plantar angle. The main pathologies caused by the reverse rotation of the coffin bone in the front limbs are the effects of increased strain on the DDFT ligaments and the navicular bone [10]. Furthermore, hyperextension of the distal interphalangeal joint, dorsal displacement of the third phalanx, and proximal displacement of the navicular bone can lead to lameness and further structural damage of the hoof. In the hindlimbs, the negative plantar angle has been associated with pathologies throughout the entire limb [11–14] and it has been shown to significantly influence the horse's posture [15].

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Modern equine activities push the limits of many structures, and any deviations from ideal conformation can lead to structural failure. Proper hoof care from an early age should be encouraged since any abnormalities of foot conformation can significantly shorten the competitive life of a sport horse [16]. Therefore, maintaining proper hoof balance is crucial for intense modern training programs.

2. Anatomical features, pathophysiology and biomechanical consequences of NPA in the hindlimbs

All the anatomical structures in the caudal part of the hoof allow the foot to absorb the impacts of body weight while enabling various movements. Three bones: distal phalanx (P3), navicular bone, and distal ½ of the middle phalanx (P2), ligaments between them: collateral sesamoidean ligaments, distal sesamoidean ligament, distal digital annular ligament, and chondro-sesamoidean ligaments; tendon of the deep digital flexor muscle (DDFT), digital cushion, joint capsule of the coffin joint, navicular bursa, the medial and lateral ungual cartilages of the distal phalanx, and the attachment of the DDFT to the coffin bone, known as fibrous enthesis, together form the navicular enthesis organ. The navicular apparatus in the equine hoof capsule is similar to human Achilles tendon apparatus in structure and function. Therefore, it can also be considered as a “premier enthesis organ” [17]. Repetitive dorsiflexion and hyperextension can lead to the degeneration of enthesis organs, both in humans and in the horse. In humans, during ankle dorsiflexion, the Achilles tendon enthesis, specifically the calcaneus, is the source of excessive compression in the Achilles tendon. In the equids, palmar and plantar processes of the coffin bone are the source of mechanical compression in the caudal part of the equine hoof when the solar surface descends pathologically below horizontal midline. Failure of premier described that increased stress organ leads to progressive lameness associated with caudal heel syndrome in humans and equids [17]. The digital cushion is a crucial anatomical structure that determines the shape and height of the caudal part of the hoof, provides shock absorption, and encourages blood return from the digit upwards. The atrophy of the digital cushion leads to descending of the palmar/-plantar processes of the coffin bone below the horizontal plane and upward displacement of the toe, which consequently causes a “reversed rotation” of the coffin bone [18,19]. An appropriate coffin bone angle is essential due to its correlation with the angulation of the other structures of the digit. The palmar angle of the pedal bone directly affects the alignment of the first, second, and third phalanges, which can result in a broken-back digit axis if the angle is negative. Widespread studies have shown that a straight bone column alignment within an equine digit provides optimal biomechanical functionality and prevents lameness [8, 9]. An external manifestation of the relationship between the pastern and the hoof wall is the hoof pastern axis (HPA). To assess HPA, a line drawn through the middle of the pastern is compared with the line running on the front hoof wall when viewed from the lateral aspect [20, 21]. Those two lines should be parallel and correspond with the angle of the shoulder. If this condition is not met, all the structures alongside the whole limb undergo excessive strain and overload. This applies to the hoof itself, as well as the tendons and joints. HPA may be ’broken forward’ when the hoof capsule is more upright or ’broken back’ in the hooves with long toe and low heel conformation. Even physiological hoof growth between shoeing periods leads to broken back HPA, which negatively influences structures around the distal interphalangeal joint and causes stress to DDFT [22,23]. Increased loading forces generated by DDFT cause pressure on the navicular bone, therefore creating a straight HPA is an effective treatment for navicular pathologies [8]. Horses that initially have weaker and lower heels are subjected to more serious alterations despite the same length of the shoeing cycle [22,24]. With the growth of the hoof, the lever arm for the DDFT increases as the COR moves back towards the heels, exposing them and the structures located within them to excessive creep forces [24]. Also, breakover time is prolonged, and the impact by landing is located directly under the palmar processes of the coffin bone rather than being absorbed through the digital cushion and other anti-concussive structures of the digit [23]. Broken back phalangeal alignment is not just a hoof issue. It has been described that increased stress of the flexor tendons and permanent pressure to the navicular region in the forelimbs causes the horse to try to relieve this stress by changing its stance and placing the feet in front of the perpendicular plane, which affects the entire musculoskeletal system [21]. Horses affected with this abnormality in the hindlimbs adopt a characteristic compensatory posture. After myofascial connections in the horse had been thoroughly examined, we started to understand why the broken back hoof pastern in the hindlimb or negative orientation of the plantar surface of the coffin bone within the hoof capsule affect many other structures throughout the entire myofascial system [25]. Also, Gellman [26] emphasized the meaning of interaction between all body structures and explained how disturbances in a single anatomical structure can negatively influence the horse’s neutral posture. Knowing that the dorsal myofascial line, which starts in the hindfoot, extends up the limb, along the back and neck into the TMJ area, helps us understand why so many structures may suffer through NPA. One of the authors described that long toe and low heel hoof conformation associated with the negative orientation of the distal phalanx in the hind hooves predisposes horses to chronic proximal suspensory overload leading to desmitis [14]. Also kinematic variables of the stride may be affected and expressed by prolonged hindlimb breakover time [23]. In addition, permanent stress on the hindquarters may lead to pain during palpation of the gluteal region [11]. A correlation between the distal phalanx’s negative or neutral plantar angle and hindlimb lameness localized to the distal tarsus and proximal metatarsus has also been described [12]. In addition, this research also indicated that reverse rotation of the distal phalanx was associated with a higher risk of lameness in the affected limb. In another study, the plantar distal phalanx angle in hindlimbs of lame horses has been compared with a control group of horses with no evidence of hindlimb lameness. Also, this study confirmed that a negative plantar angle created lameness potential in hindlimbs but in contrast to other studies, the most common source of lameness was localized in the stifle joint [13]. Research conducted by Walmsley et al. indicated that Thoroughbred racehorses with negative hindlimb solar angle were more likely to suffer from subchondral bone injury at the plantar aspect of the condyles of the third metatarsal bones [27]. In conclusion, only straight alignment of the hoof pastern axis enables optimal distribution of impact forces during landing on the ground. It provides healthy joint spacing, minimizes the negative impact of ground reaction forces acting on the distal limb, and places the hoof in the optimal position under the limb for effective stress distribution to reduce injury incidence [28,29]. A crucial factor determining HPA is the coffin bone position within the hoof capsule; therefore, it should never be ignored.

3. Diagnostic features of negative plantar angle

Assessing hoof conformation and phalangeal alignment should always be a part of a holistic approach to diagnosing horses with hindlimb orthopedic issues. Recognizing abnormal conformation of the hind hooves is crucial for maintaining proper shape and function. We can start by viewing the limb laterally to assess HPA, as it is crucial for proper hindlimb biomechanics. A broken back HPA may be an external manifestation of pathological changes within the hoof capsule, together with the long toe and low heels appearance of the hoof. Unfortunately, once external signs are recognizable, damage to the internal structures of the hoof has already occurred. Progressive heel collapse is the result of digital cushion atrophy. When the digital cushion diminuates, excessive pressure on the heel tubules occurs, causing them to fold inward and forward rapidly [30]. While evaluating such a hoof from behind, the frog is visible and it prolapses between the horseshoe branches and the heels lying against the shoe. The frog is then overloaded during weight bearing, which often causes reluctance to lift the opposing limb off the ground [20]. We can evaluate the digital cushion quality by palpating the bulbs. Specifically, the thumb is placed between and on top of the horse's heel bulbs and the other fingers are placed over the frog, making it possible to evaluate digital cushion consistency. A healthy digital cushion should feel quite firm [18]. The external morphology of the caudal hoof indicates if the digital cushion is developed correctly. We can expect digital cushion atrophy in a hoof that displays collapsed heels, a prolapsed frog, and manifests a typical long toe and low heel appearance. All those factors lead to an increased heel-to-toe ratio, predisposing horses to an increased risk of lameness [19]. It is possible to predict the orientation of the coffin bone within the hoof based on the evaluation of the external appearance of the hoof capsule. In advanced cases of pathologies within caudal hoof structures, the plantar processes of the distal phalanx are descending below the horizontal plane, and the dorsal edge of the coffin bone migrates toward the dorsal hoof wall, causing a bull-nosed appearance. Concurrently, the plantar margin of the third phalanx becomes negatively angled. The main external features of the hooves with NPA are a long toe and low heel conformation, the disparity in the growth rings, and the 'bull nose' forming on the front wall of the hoof (Fig. 1).

Radiological features of the NPA are similar in the front and hindlimbs: hyperextension of the distal interphalangeal joint, dorsal displacement of the third phalanx, proximal displacement of the navicular bone, and shifting the center of rotation of the coffin joint to a more plantar direction (Fig. 2).

NPA severity can be classified into four grades (I to IV) based on the external and radiological characteristics of the hoof and its response to farrier intervention. This grading system helps determine the most suitable treatment options and provides an accurate prognosis for horses with NPA [31]. (Table 1).

Horses affected with NPA also adopt a characteristic posture, placing the hindlimbs underneath and the hooves are placed rostrally in relation to the vertical axis of the whole limb (Fig. 3).

4. Treatment options for hind feet affected with NPA

While the hooves of the front and hindlimbs are anatomically similar, their biomechanical differences reflect their distinct functions. Whereas the front limbs are responsible for weight bearing, the main task of the hindlimbs is propulsion and traction. Therefore, the shape and angulation of the hoof capsule in the hindlimbs is quite different than in the front limbs, being more upright and narrow. The sole is more concave, and the toe is more pointed, enabling effective propulsion and determining the shape. Our knowledge about the hooves of the hindlimbs is still limited because, for many years, the main focus was on the forelimbs. Trimming and shoeing principles are based on the fundamental statement that appropriate hoof balance is achieved when performance is enhanced and long-term athletic ability is minimally affected. Following this statement, there is no reason why the standards for trimming the front hooves should not apply to the hind hooves. Therefore, the principles of trimming and shoeing the hindlimbs are based on the idea that proper hoof balance is attained when performance is improved, and long-term athletic ability is minimally affected. This balance can be achieved by evaluating the horse's conformation and athletic activities in detail. It should involve both static and dynamic assessments and address any underlying orthopedic issues. The main tips for corrective trimming and shoeing based on biomechanical principles are: (1) Correcting any hoof imbalance in both mediolateral and craniocaudal planes before applying any shoeing techniques; (2) Providing shock absorption; (3) Ensuring proper hoof slip during the secondary impact phase; (4) Optimizing pressure distribution during the support phase depending on underlying pathology; (5) Promoting and optimizing brakeover; (6) Enhancing hoof mechanism [32]. Adhering to these guidelines helps the hooves effectively absorb concussions and reduces strain on the musculoskeletal system. One positive aspect considering the hind hooves is that heel damage is generally easier to address than in the front limbs. This is due to the distinct biomechanical

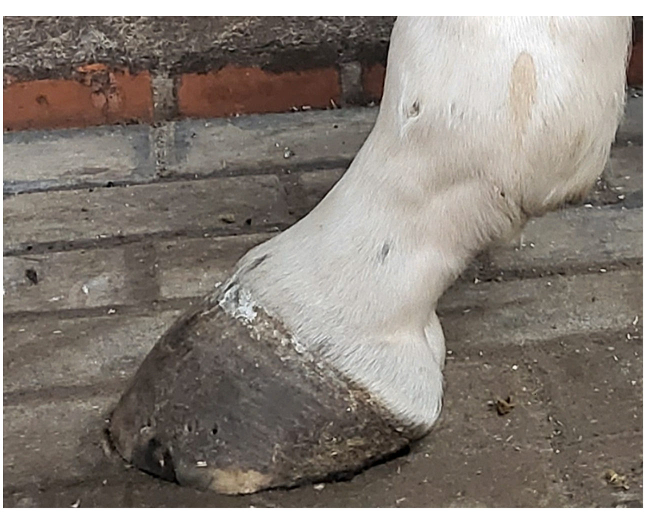

Fig. 1. External features of hoof capsule with negative plantar angle showing long toe with bullnose formation and low heel conformation.

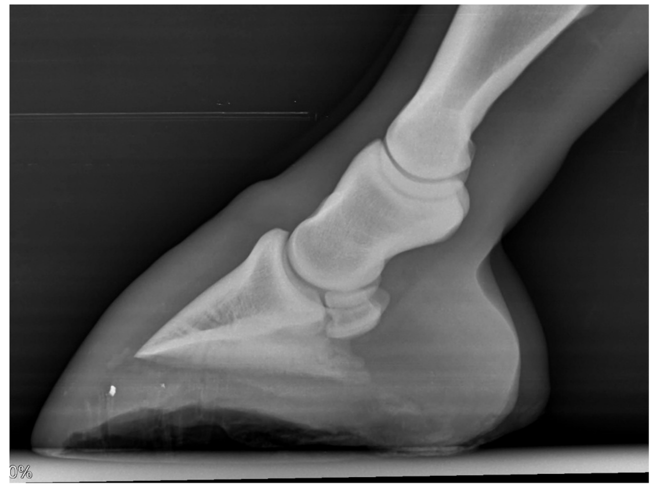

Fig. 2. Radiological features of the hoof with negative plantar angle: hyperextension of the distal interphalangeal joint, dorsal displacement of the third phalanx, proximal displacement of the navicular bone, broken back HPA and upward displacement of the tip of the coffin bone.

Table 1
NPA grading system adapted from Floyd [31].

Grade	Description and prognosis
I (mild)	Encloses hooves with sufficient sole depth under the tip of the coffin bone in which the normal digital alignment can be restored just with corrective trimming.
II (moderate)	The sole depth is limited, and after trimming, the only that can be achieved is a neutral angle of the plantar surface of the third phalanx.
III (severe)	Heels, bars and digital cushion are severely compromised and restoring a neutral or positive plane of the plantar edge of the coffin bone and realignment of hoof pastern axis can be achieved only with trimming followed by orthopedic shoeing
IV irreversible	Affected foot is characterized by accompanying vertical orientation of the third and second phalanx, and severe hyperextension of the DIP joint, which leads to a post-legged stance. This cannot be corrected even to create a neutral plantar angle. However, the author described it only to be seen in halter bred American Quarter Horses. Under our conditions we met this grade only in one case of a complete rupture of DDFT.

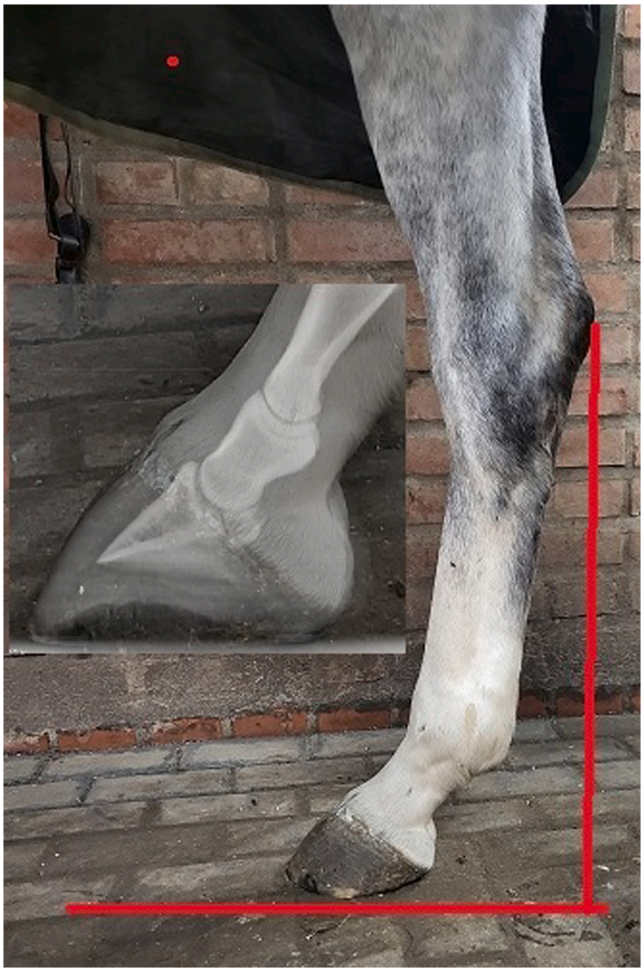

Fig. 3. The influence of negative plantar angle on hindlimb posture and a corresponding radiogram of the affected hoof.

features and anatomy of the hindlimbs. In the event of mild structural damage to the hind hoof, a positive plantar angle can often be restored immediately through corrective trimming alone. If there is enough sole depth at the toe, the front part of the sole, from the widest part of the foot forward to the toe, should be trimmed in a wedge-shape to create a neutral to 3-degree plantar angle of the coffin bone. The sole in the region of the heels should only be gently trimmed to move the weight-bearing surface back to the widest part of the frog. When there is insufficient sole depth under the toe, corrective trimming must be supported by shoeing techniques to restore a positive plantar angle and normal hoof alignment. After appropriate farrier intervention, posture improvement occurs immediately [31] (Fig. 4).

The most effective way of improving hoof pastern alignment and NPA is using wedges to encourage a neutral morphology. Any heel elevation should only and exclusively be used with appropriate pads and sole packing to provide immediate frog support, which positively impacts the hoof's internal structures. Supporting a frog with a pad and packing material eliminates the distance that the frog is descending before being loaded, and this can significantly diminish the undesirable effects of wedge influence on heel crushing, which has been widely discussed for years [33] (Fig. 5).

Simon Curtis emphasized that an essential factor in restoring a straight HPA is unloading the heels to promote hoof growth in the caudal part of the hoof. It can be achieved by trimming back the heels to return them to a more plantar position. This, along with fitting a shoe that contains additional caudal hoof support and is filled with dental impression material, helps distribute the load more evenly across the

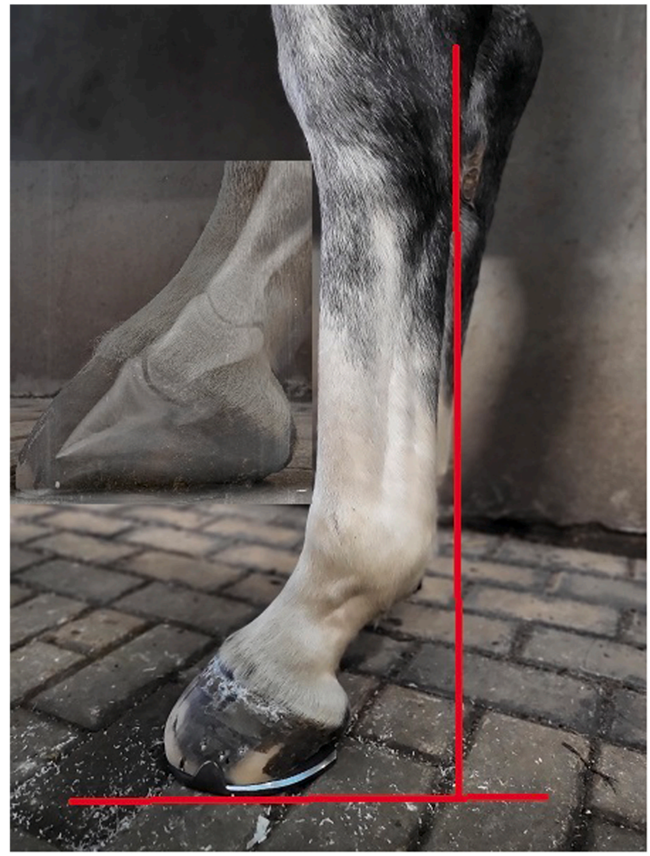

Fig. 4. Posture improvement after corrective trimming and shoeing.

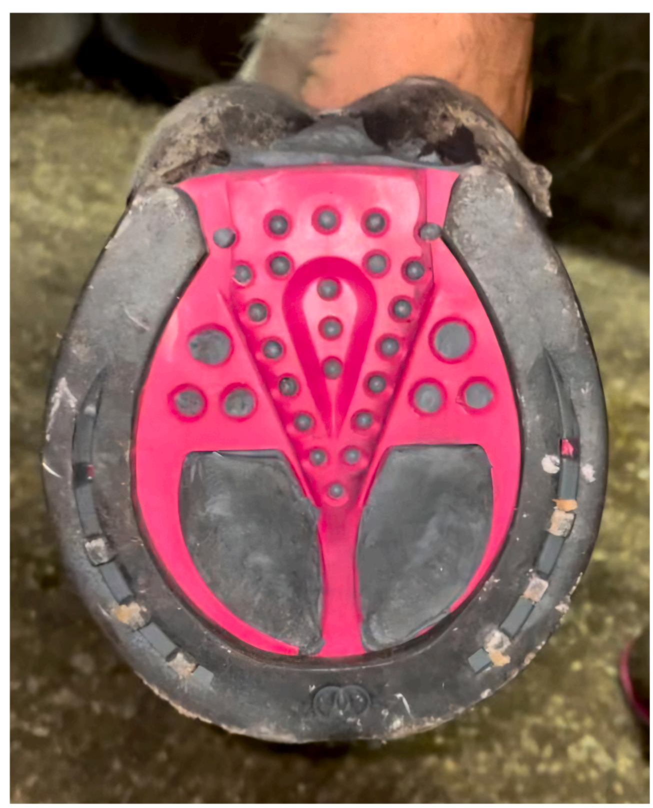

Fig. 5. Frog support with a pad and packing material.

entire foot. If elevating the heel is essential for improving HPA, digital support made from impression material should be included in the shoeing technique. Any heel elevation should only be a temporary solution for a limited period. In cases with NPA but without broken-back HPA, flat spider pads with packing material supporting the frog are recommended.

5. Prehabilitation options for horses affected with negative plantar angle

Prehabilitation **is** *a preventive* approach designed to maximize health and wellness and minimize individual risks for injury and disease. Unlike rehabilitation, which focuses on recovery after an injury, prehabilitation aims to prevent injuries before they happen [34]. An important method of prehabilitation in performance horses is eliminating restrictions resulting from poor hoof conformation. Hind hoof balance directly impacts hindlimb posture and strain on the lumbosacral spine [15]. A negative plantar angle leads to a canted-in posture, **requiring** increased muscular effort to maintain. As horses typically spend 22–23 hours a day in a standing position - eating, socializing and sleeping, it is extremely strenuous and a lot of neuromuscular effort is needed to stabilize their posture. Normal neutral posture (NNP), typically seen in healthy and feral horses, facilitates equal leg movement in all directions. Abnormal Compensatory Posture (ACP), known as canted-in or camped-under posture, is a narrow stance seen in some horses, caused by structural distortions in critical mechanoreceptor-rich anatomic regions like the hooves, the stomatognathic system or the upper cervical area. In such individuals, incorrect proprioceptive signals modify neural processing and motor output. To stand stable in a canted-in posture, horses need to be twice as stiff than that needed for NNP [26]. Therefore, prehabilitation directed in strengthening this group of postural muscles could help those individuals withstand the effort needed to maintain a stable position. Designing an appropriate series of exercises or implementing various physical treatments could help to be one step ahead to prevent injury before hind hoof balance can be restored. Chronic gluteal pain caused by a crouched posture can be effectively managed with magnetic field therapy and therapeutic ultrasound [35]. Functional electrical stimulation (FES) has proven effective for managing chronic thoracolumbar pain [36]. It can also be helpful in neutralizing overall stiffness caused by abnormal compensatory posture (ACP). Due to the increased neuromuscular effort involved in maintaining ACP, activation of the core musculature positively impacts horses affected with NPA in the hindlimbs. One of the most important core muscles of the equine back is the multifidus muscle. An effective increase of its cross-sectional area can be achieved through dynamic mobilization exercises or baited stretches when continuously repeated over at least 12 weeks [37]. A similar effect may result from FES application in the thoracolumbar region of the affected horses [36]. Walking over ground poles and raised poles and trotting over raised cavalleti at a slow trot is also beneficial in core strengthening [38]. Because incorrect proprioceptive signals modify neural processing in horses standing in a camped-under stance, it is important to incorporate proprioceptive training of the hindlimbs. For this purpose, a therapeutic approach utilizing lightweight tactile stimulators (weighing 55 g) attached around the hind pasterns is worth considering. This method helps to strengthen the muscles of the hindlimbs. [39].

6. Rideability and performance issues in horses with negative plantar angle

From a welfare perspective, any pain-related conditions resulting in behavioral changes should be thoroughly investigated to explain their underlying cause. Horses may exhibit loss of hindlimb propulsion, bucking, rearing, or overall unwillingness to work. Sometimes, such horses are simply described as "bad-tempered." [40]. Behavioral alterations indicative of pain have also been reported in other species, such as dogs and cats [41]. Recognizing this fact should make us more aware of how even slight behavioral changes could indicate a painful condition somewhere in the body. Profound body balance is ensured by myofascial kinetic lines connecting movements between the spine and the extremities. Because of the myofascial connection of the P3 in the hindlimb up to the pelvic region and further forward with the trunk, it becomes clear why many horses with negative plantar angles are performing below their expectations [25]. In the authors' experience, horses with a negative plantar angle may exhibit a lack of propulsion, an inability to fully engage their hindlimbs, and a general reluctance to move forward when ridden. As modern equine activities push the limits of certain structures, any deviations from ideal conformation can lead to structural failure and discomfort. After recognizing any decline in the horse's performance, a thorough orthopedic examination should follow. If the horse is considered not lame but still manifests the presence of musculoskeletal pain when ridden, it needs to be re-evaluated. Diagnostic anesthesia should be implemented after excluding ill-fitting saddle and rider-related issues [42]. In the case of NPA, diagnostic anesthesia pertains to the hoof itself or other affected limb structures resulting from abnormal compensatory posture. These structures include the proximal suspensory ligament [14], tarsus [12], stifle [13], proximal metatarsus [27], thoracolumbar spine [15] or gluteus muscle group [11]. Behavioral changes indicating hindlimb hoof imbalances can be assessed using a ridden horse pain ethogram [42]. After excluding the previously mentioned factors, ensuring a proper saddle fit, and confirming the angle of the coffin bone via radiology, we can consider NPA as a contributing factor to the horse's rideability issues. Horses expend twice the amount of neuromuscular effort to stand and work in a camped-under posture, which leads to muscle fatigue. This kind of maladaptive stance puts increased stress on the hindlimb joints, ligaments, and muscles and the thoracolumbar spine. After fixing the structural problems in the hooves, the horse's posture reverts to neutral (standing square) [26]. A square stance is considered as healthy in quadruped. Therefore, during the dressage test, the horses should stand square for the salute and the halt. If a horse has a negative plantar angle, achieving this stance can be impossible, and it is viewed as a serious rideability issue. Therefore, for optimal performance ability, individual foot care programs should be implemented to prevent or minimize the occurrence of undesired overload of anatomical structures within the hoof capsule and the entire limb.

7. Conclusion and scope for future research

Monitoring hoof and posture morphology is essential for a proactive approach to horse welfare and soundness. Designing a suitable series of exercises for horses with negative plantar angles is akin to staying one step ahead of potential injuries. Since horses spend a significant amount of time standing throughout their lives, developing prehabilitation programs for those with hoof imbalances can greatly improve their comfort and athletic performance. Many authors have already described the negative impact of hind hooves imbalances. The summary of potential biases or variations in study populations shows how diverse this topic is (Table 2).

Today's equine work is very close to reaching the limit in terms of the strength of some structures, and any deviations from the perfect conformation can contribute to the breakdown of these structures. Considering how the conformation of hindlimb hooves affects the entire body, it would be advisable to explore the details of hindlimb biomechanics to monitor the impact of a negative plantar angle on the load of the limb. Since the conformation of hindlimb hooves affects the entire body, examining the intricate details of hindlimb biomechanics is advisable to understand how a negative plantar angle impacts limb loading. According to the authors, biomechanical studies using surface electromyography of the hindlimb muscles, lumbosacral region, and vertebral column flexors and extensors would enhance our understanding of how specific muscles compensate for the canted-in posture

Table 2
Variations in study design and population of horses affected with NPA.

Author	An orthopedic issue that is predisposed by a negative palmar angle.	Breed ang age	Discipline	Management	Comment
Dyson, 2017	Chronic proximal suspensory overload leading to its desmitis in hindlimbs	Horses in all athletic disciplines and of all ages	All athletic disciplines, especially dressage horses	Treatment of injury and correction of foot imbalance - egg bar shoes are used to reduce extension of the fetlock	Some horses can develop secondary problems (pain from sacroiliac joint, thoracolumbar regions and, pain associated with preexisting impinging dorsal spinous processes)
Mansmann et al., 2010	Gluteal region pain	Various breeds, 4–24 years old	Various disciplines (medium or lower level adult performance horses)	Shortening the toe (trimming to move the load-bearing surface further back under the coronary band - ideally to the widest part of the frog at the heels; the shoe was then selected and positioned such that the breakover point at the toe was located no more than 15 mm forward of the tip of P3, using the apex of the frog as an external landmark; in horses with very low heels, the farrier applied a 3° heel wedge for a minimum of one shoeing cycle)	Shortening the toe with trimming and shoeing, or trimming alone in the barefoot horse, alleviates the gluteal pain in a relatively short period (days or weeks). In cases when the toe length or gluteal pain was adversely affecting the horse's comfort or function, then one could also expect an improvement in the horse's gait and performance after remedial trimming and/or shoeing
Clayton et al., 2010	Significant changes in limb coordination patterns and in the diagonal synchrony of limb movements at the trot	Don't provided	Mares, don't provided	Farriery modifications designed to slow protraction of the hind limbs include sparing the toe and/or lowering the heels to produce a more acute hoof angulation	-
Clements et al., 2019	lameness originating from the stifle joint	Various age and breeds	Various disciplines	Don't provided	The study indicates a strong correlation between negative palmar angle and lameness in the pelvic limbs; barefoot horses in the lameness group tended to have more positive PDPA angles than shod horses, possibly indicating some protective effect of being barefoot
Walmsley et al., 2019	Injuries in the metacarpo(tarso) phalangeal joint	Thoroughbred	Racehorses (horses presenting with lameness or poor performance were included, may not be representative of the general population of racehorses)	Don't provided	Injuries in the metacarpo(tarso) phalangeal joint, potentially contributing to fatigue and the development of subchondral bone damage

observed in horses with NPA. Electromyography could be adapted to detect early signs of muscular overload and fatigue in hindlimbs affected with NPA to prevent possible foot-related lameness. Superficial EMG could also be helpful in objectively evaluating the influence of various farriery interventions used to correct HPA and NPA and to monitor muscle activity changes within a shoeing period. Considering that the consequences of NPA may be responsible for the premature end of competitive performance, we should focus on novel methods for monitoring the influence of NPA on hindlimb health.

Ethical animal research

Research ethics committee oversight not required by narrative review.

CRediT authorship contribution statement

Domańska-Kruppa Natalia: Writing – original draft, Supervision, Resources. **Stefanik Elżbieta:** Writing – review & editing, Visualization. **Domański-Kruppa Felix:** Project administration, Data curation, Conceptualization. **Szymczak Michał:** Visualization, Supervision, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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