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ORIGINAL RESEARCH

Effect of gamified perceptual learning on visual detection and discrimination skills in equine gait assessment

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Abstract

Background: Visual assessment of equine lameness is an everyday veterinary task suffering from poor diagnostic accuracy. The aim of this study was to quantify the impact of the perceptual learning game 'LamenessTrainer' on skill development.

Methods: Thirty-six undergraduate veterinary students engaged in four game modules teaching the assessment of fore- and hindlimb lameness. Computer animations of horses in this game displayed 0% (sound) to 70% (moderately lame) vertical movement asymmetry of head and pelvis. Performance, learning effects, diagnostic accuracy, detection thresholds and survey responses were analysed.

Results: Following staircase learning, more than 80% of students reliably classified horses with ≥20% asymmetry for forelimb lameness, ≥40% asymmetry for simplified hindlimb lameness and ≥50% asymmetry for realistic hindlimb lameness. During random presentation, on average 82% of sound and 65% of lame horses were assessed correctly during forelimb lameness evaluation, dropping to 39% of sound and 56% of lame horses for hindlimb lameness.

Conclusion: In less than two hours, systematic perceptual learning through deliberate practice can develop visual assessment skills to an accuracy level comparable to expert assessors scoring the same animations. Skills should be developed further to improve misclassifications of sound and mildly lame horses, especially for hindlimb lameness evaluation.

INTRODUCTION

In both human and veterinary medicine, many diagnostic tasks rely on the ability to see a deviation from what is considered 'normal'. The need to better develop such visual skills has long been highlighted in human medicine, illustrated for example in the area of interpreting radiographs and other medical images.[1–5] In veterinary medicine, a lack of diagnostic accuracy for common visual tasks such as gait assessment in horses and other animals has equally been recognised for decades, mirroring difficulties observed for human gait evaluation.[6–11]

The visual assessment of gait is an important aspect of equine orthopaedics, as an asymmetrical gait cycle is often diagnostic of underlying pathological issues.[12,13] The ability to notice subtle movement asymmetry allows for the important early detection and management of pathology related to lameness. Lameness assessment is one of the most common primary care and specialist tasks,[14,15] with roughly one third of UK horses with health problems being lame according to the Blue Cross's National Equine Health Survey.[16,17] However, subtle and mild lameness is inherently difficult to reliably classify visually.[8,18,19] This leads to unreliable judgements both with regard to overlooking clinically relevant lameness and mistaking horses with no real movement abnormality for lame.[20] Consequently, outcomes of pre-purchase examinations and medical assessments may return an incorrect recommendation.

To date, systematic training of how to assess horses for lameness reliably, using a standardised visual assessment protocol, remains lacking. This results in inconsistent approaches and skills between different equine clinicians.[21] Thus, variation in the selection, interpretation and weighting of different indicators of lameness has been flagged as a likely contributing factor to unreliable visual gait assessment.[8] Similarly, students – especially those in early training – report a large variation in their use of lameness indicators.[22] In stark contrast to this variation in visual assessment approaches, there is ever increasing clarity on the key movement features correlating with lameness coming out of the biomechanics literature:[13,23,24] in essence, evaluation of vertical head and pelvis movement for movement asymmetry is the most robust predictor of lameness. Spotting this asymmetry can be learned systematically.

In education theory, expertise can be viewed as the result of deliberate practice,[25,26] where the act of repeatedly practising and refining a skill accounts for large proportions of expertise levels reached. Important to deliberate practice is feedback, and the acquired learning can be graphed through learning curves.[27] Perceptual learning[28] describes deliberate practice applied to sensory information, where a student can develop detection skills based on repeated exposure to perceptual stimuli. Perceptual learning offers a framework for the development of expertise in most visual tasks.[28–30] Central to perceptual learning are – among other aspects – improved pattern recognition, a shift in attention towards the most important aspects characterising the task and increased ability to discriminate between similar stimuli.[28,31] This can lead to the detection and differentiation of stimuli with sometimes astonishing precision.[28,29,31,32]

Current training of lameness assessment skills for veterinary students typically involves video case-studies in lectures, practical work with clinicians on real cases during clinical rotations and key textbooks.[33–35] Limitations of these methods are that a) the caseload in clinics is varied, does not progressively increase from easy to complex cases and is often biased towards difficult cases in university referral (teaching) hospitals, b) the real-time nature of viewing lameness in practice does not allow review of the material, c) textbooks are not dynamic and rely on descriptions/illustrations, d) videos can be easily memorised, preventing deliberate practice and e) literature as an independent learning resource can lack the structure and scaffolding required for a useful learning experience.[37,38] Improved training of lameness evaluation skills using additional means is therefore paramount to ensuring accurate lameness assessment. This is the reason why we developed the free online resource LamenessTrainer (www.lamenesstrainer.com).

We developed the intelligent online game LamenessTrainer using 3D animations of horses, based on the principles of perceptual learning, in order to overcome shortfalls in existing lameness assessment training tools. The aim of this study was to quantify the impact of a perceptual learning approach on asymmetry detection and differentiation skills in a cohort of 3rd year undergraduate veterinary students. The objective was to evaluate the potential of the LamenessTrainer game for the development of visual detection and discrimination skills and expertise. We hypothesised that engagement in this perceptual learning approach would improve the detection threshold for gait asymmetry compared to untrained baseline performance, and that students would develop visual discrimination performance levels closer to that of experienced veterinarians.

MATERIALS AND METHODS

Participants

Ethics approval for this study was granted through the Royal Veterinary College's (RVC's) local ethics committee (URN 2014 0110H). Participants were recruited, via email invitation, from all third-year students on the BVetMed programme during their musculoskeletal system teaching. Of nearly 250 invited students, 72 engaged in parts of the game, of which 36 (half) engaged in all four game 'Modules', making up the sample analysed in this study. This uptake level reflects our experience that around 10–15% of veterinary students are specifically interested in working in equine practice.

The RVC 5-year undergraduate Bachelor of Veterinary Medicine curriculum is a horizontally and vertically integrated spiral curriculum; students visit the musculoskeletal system three times in the classroom, and this was the final visit. Participation was incentivised by two prizes (gift vouchers to spend at an online retailer), one for a randomly selected student from all those who engaged in all parts of the game and one for the highest total score across all parts of the game.

Students could engage in the material anywhere they liked, as long as access to a PC/laptop and internet were available. Students started the study by signing an online informed consent form and were invited to complete a questionnaire before and after playing the game. Some of the students had access to other lameness teaching materials (videos) prior to commencing the game, and previous lectures had covered lameness assessment. Since it was not possible to track or verify which students had engaged in which additional learning material prior to commencing the game, all data were pooled.

Definitions

In the light of terminology having different implicit meaning in different contexts and domains, we used terms with a focus on the subject area based on the following definitions:

- Sound: a horse not showing any signs of lameness, in this controlled study displaying 0% vertical displacement asymmetry of head and mid-pelvis. In the context of this study, soundness only refers to the absence of lameness.
- Lame: a horse showing movement asymmetry of head and pelvis indicative of an underlying medical issue, in this controlled study displaying 10-70% vertical displacement asymmetry of head and

FIGURE 1 The final animated horse model and its principal vertical movement. Left - wireframe view with skeleton, middle - fully shaded and lit, right - vertical movement trajectory for a sound (grey) and lame (red) horse (RF: stance phase of the right forelimb, LF: stance phase of the left forelimb)

mid-pelvis. In line with most definitions, lameness is considered a clinical sign.

3D animations of sound and lame horses

Animations of trotting horses were developed based on a multi-step process: firstly, motion capture data were recorded from a Thoroughbred horse at the trot over ground. Secondly, derived joint angles and upper body displacement trajectories (averaged across multiple trials and mirrored between left and right limbs for perfect symmetry) were then applied to a 3D horse model (Figure 1) using Maya and MotionBuilder (Autodesk, USA). Thirdly, four different near-photo-realistic coat colours were applied to the horse model, and random tail movement was animated using the physics engine in MotionBuilder. Fourthly, using the insights from fundamental equine locomotor biomechanics,[23,39,40] vertical movement of head and sacrum were simplified to a sine-wave, and asymmetry reflective of various lameness degrees (Figure 1) was introduced. This replicated the well-documented, systematic changes occurring to vertical head and pelvis movement during lameness.[9,23,41–44] Asymmetry was defined as the difference between the two upward movement amplitudes of head or mid-pelvis between the two steps of one stride (Figure 1), representing the most common lameness pattern[45] also described as impact lameness.[46] This was done separately for forelimb lameness (head movement trajectory modified) and hindlimb lameness (pelvis movement trajectory modified) and resulted in animated clips with 10%, 20%, 30%, 40%, 50%, 60% and 70% vertical movement asymmetry.

In practice, on the UK scale, asymmetry of 40-50% corresponds to approximately grade 2-3 out of 10 and asymmetry of 70% to approximately grade 4-5 out of 10 (Sandra D. Starke, unpublished data). On the American Association of Equine Practitioners' (AAEP) scale, 44% head movement asymmetry/40% sacrum movement asymmetry previously mapped onto grade 1 out of 5, 86% head movement asymmetry/60% sacrum movement asymmetry onto grade 2 out of 5.[23] On a four-point scale, 30% head movement asymmetry/25% sacrum movement asymmetry previously mapped onto grade 1 out of 4, 45% head movement asymmetry/37% sacrum movement asymmetry onto grade 2 out of 4.[9,41] Hence, overall, this study taught lameness assessment skills for lameness of up to approximately half the maximum severity level, respectively moderate lameness. It did not include 'hopping lame' horses and focussed on lameness degrees where horses still exhibit two oscillations of vertical movement during a stride.

Gamified training

Perceptual learning paradigm

The foundation for the training was a feedback-based perceptual learning paradigm, utilising an 'adaptive staircase' design from psychophysics to gradually develop discrimination skills. In practice, this meant that a student started with a prominent difference between 'normal' and 'lame' (having to discriminate between animations with either 0% or 70% movement asymmetry). Once the student reliably differentiated between these horses, the game then automatically increased the difficulty level by lowering the asymmetry degree (to 60%, 50% and so on). When the student failed to reliably discriminate between sound and lame, asymmetry was automatically increased again to make differences easier to see. This approach has the benefit of teaching discrimination skills, helping students to set their criterion between sound and lame horses appropriately following fundamentals of signal detection theory.[47]

Game design

Four game 'Modules' were created: Modules 1 to 3 were built around adaptive staircase learning, teaching assessment of forelimb lameness (Module 1) and hindlimb lameness through two stages (Module 2 and 3). For hindlimb lameness, in Module 2 a simplified pattern was shown which only consisted of the pelvis translating, but not rotating. In Module 3, the realistic and hence complex pelvis movement pattern was shown, which consists of both translation and axial

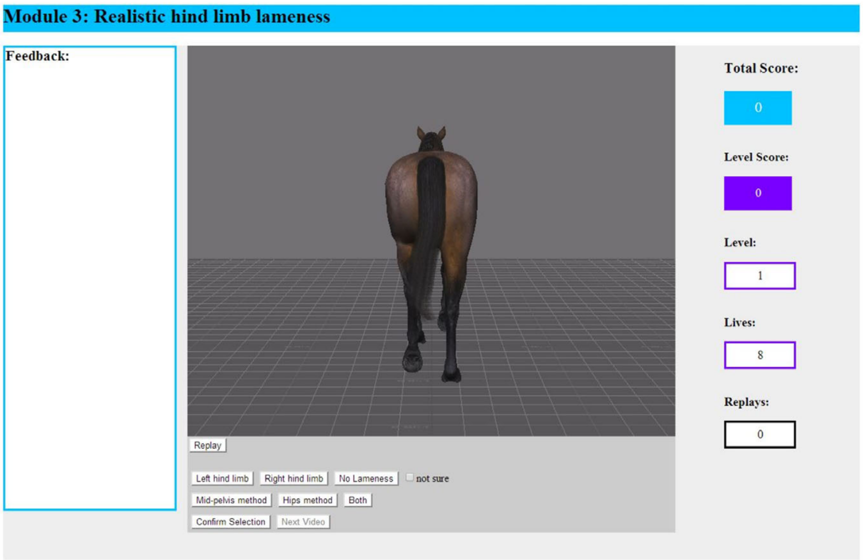

FIGURE 2 Example game interface for Module 3 which teaches detection of realistic hindlimb lameness. For each evaluation, feedback is provided in the box on the left after submitting an assessment. The interface has since been updated for the current version of the LamenessTrainer online

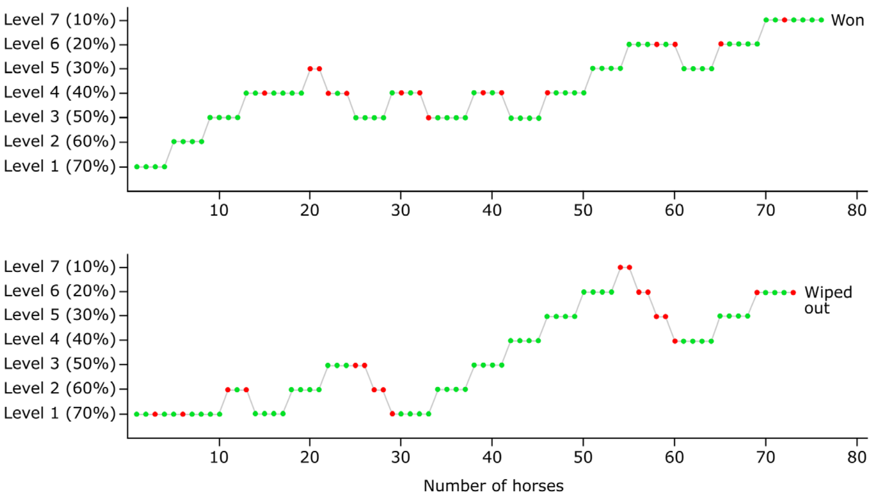

FIGURE 3 Progression through a Module, with an example of a student who ‘won’, respectively successfully completed all seven levels (top) and a student who ‘wiped out’, respectively lost all eight lives before completing all seven levels (bottom). Green – correct assessment of a given horse, red – incorrect assessment

rotation.[48,49] The module used symmetrical pelvic rotation across all lameness grades. All three modules featured an introductory video tutorial explaining lameness indicators and how to identify the affected limb (in short, ‘nod down when sound foot is on the floor’ for forelimb lameness and ‘hike up when pushing off sound limb’ for hindlimb lameness). This was followed by a warm-up exercise, where students were shown 10 horses in random order without feedback to estimate baseline pre-training ability. Module 4 showed 136 horses in random order to give students the opportunity to apply their new skills in a scenario more similar to real life situations, where the degree of lameness is unknown.

The interactive game was developed using html5, javascript, php and MySQL. Each Module of the game was presented on an interactive game interface (Figure 2) which allowed the student to interact with the video, keep track of his/her progress, submit decisions and receive feedback on each evaluation. The software was run on a local network. For each of Module 1 to 3, 28 lame horses (seven asymmetry levels and four coat colours) and 12 sound horses (three separate renders and four coat colours) were exported as .mp4 clips. Each clip showed 10 strides (20 steps). For Module 4, horses with different coat colours were exported, with a total of 68 horses shown in front- and 68 shown in rear view.

Game mechanics

In Module 1 to 3 (adaptive staircase learning, Figure 3), participants had to assess four horses in a row correctly to progress between seven difficulty ‘levels’ (representing the seven asymmetry degrees from 70% at level 1 down to 10% at level 7). Each correct assessment scored points. Horses could be reviewed as often as desired, although one point was subtracted per review for the first two reviews. After the first two reviews, no further points were deducted for any additional reviews. For each horse, the likelihood of choosing the correct assessment by chance was 33%; the likelihood of assessing four horses correctly in a row by chance alone was hence 1%. If one horse was assessed incorrectly on a given level, points for the current level were reset to zero. If two horses were assessed incorrectly, the learner dropped back a level and lost a ‘life’.

For each of Module 1 to 3, eight lives were available; if all of them were lost, the student was 'wiped out'. If the game was completed without losing all lives, the student 'won' (Figure 3).

In Module 4 (random presentation), 136 horses had to be evaluated in random order, with 68 horses shown in front view (for assessment of forelimb lameness) and 68 horses shown in rear view (for assessment of hindlimb lameness). Of the 68 horses, eight showed movement asymmetry for any given level (ranging from 10% to 70% as before), and twelve horses were sound. Five points were awarded for each horse evaluated correctly, while 2 points were subtracted for each horse evaluated incorrectly. The score could not drop below zero, and students could review each horse as many times as they liked without an effect on points accumulated. As there was no requirement to evaluate consecutive horses correctly, the chance level for Module 4 was 33%.

Data collection and analysis

All interactions with the online material were logged and stored anonymously in a MySQL database and exported for further analysis in Matlab (The MathWorks) and Excel (Microsoft Corp.). Data of only those participants who engaged in all four modules were analysed in order to track progress across modules without introducing bias.

Improvement in the correct classification of horses at a difficult discrimination level (20% movement asymmetry) as lame in the correct limb was assessed by comparing baseline performance during the warm-up with the ability of the student to successfully pass level 6 in the game. A Related-Samples McNemar Change Test was conducted to compare performance before and after training.

For Module 1 to 3, the percentage of students correctly assessing horses at each asymmetry level, both with regard to detecting the general presence of lameness and also classifying the correct limb as lame, was calculated. The duration played, highest level passed, average number of repeat views per clip, total number of step backs (return to an easier level) and total number of horses assessed were extracted for summary statistics.

For Module 4, the percentage of correct classifications as sound and lame was calculated as described above, and reasons for incorrect classifications were derived. A paired t-test was used to compare results between assessment of sound and lame horses and between fore- and hindlimb lameness. For each participant, the visual asymmetry detection threshold was approximated for fore- and hindlimb lameness using binary logistic regression in Palamedes (http://www.palamedestoolbox.org/). This threshold estimates the asymmetry level at which a participant correctly detects the presence of lameness in 50% of cases. This threshold is often used to approximate the point beyond which the eye cannot detect any further difference in stimulus (also termed the 'just noticeable difference', in this case, movement asymmetry of the horse). Signal detection measures of diagnostic accuracy were calculated for correct classification as generally sound or lame (irrespective of classifying the correct limb as lame): sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) were calculated as

TABLE 1 Signal detection measures of diagnostic accuracy

	Forelimb lameness	Hindlimb lameness
Sensitivity	0.89 (0.07)	0.85 (0.09)
Specificity	0.82 (0.19)	0.39 (0.22)
PPV (1:1 ratio)	0.86 (0.13)	0.60 (0.09)
NPV (1:1 ratio)	0.89 (0.05)	0.68 (0.20)

Diagnostic accuracy for the assessment of horses with varying asymmetry levels presented in Module 4. Presented are the mean (SD) for sensitivity (the proportion of all lame horses correctly classed as lame), specificity (the proportion of sound horses correctly classed as sound), positive predictive value (PPV, the likelihood of a horse classified as lame truly being lame) and negative predictive value (NPV, the likelihood of a horse classified as sound truly being sound). PPV and NPV are calculated for an assumed 1:1 ratio of sound to lame horses.

$$\text{Sensitivity} = \text{TP}/\,(\text{TP} + \text{FN}) \tag{1}$$

$$\text{Specificity} = \text{TN}/\,(\text{TN} + \text{FP}) \tag{2}$$

$$\text{PPV} = \text{TP}/\,(\text{TP} + \text{FP}) \tag{3}$$

$$\text{NPV} = \text{TN}/\,(\text{TN} + \text{FN}) \tag{4}$$

These metrics were based on the count of true positives (TP, lame horse classed lame), false negatives (FN, lame horse classed sound), true negatives (TN, sound horse classed sound) and false positives (FP, sound horse classed lame). For PPV and NPV, the ratio of sound to lame horses was assumed as 1:1. Table 1 explains the meaning of these metrics further. Paired t-tests were performed to compare metrics between assessment of fore- and hindlimb lameness.

Answers from questionnaires administered before and after training were extracted for participants who had engaged in all modules. Paired t-tests were performed to compare answers before and after training.

RESULTS

Participation and participant profile

Of the 36 participants (all of which completed the initial questionnaire), 75% had had previous opportunity to practice lameness detection skills. Of those with prior experience, 33% reported participating in/observing lameness work-ups with clinicians, 37% reported assessing their own/others' horses independently, 100% reported assessing videos (e.g. in teaching sessions), and 4% reported other opportunities. The mean (SD) approximate number of horses previously evaluated was 19 (32), ranging from 3 to 150. Students rated the overall perceived difficulty of

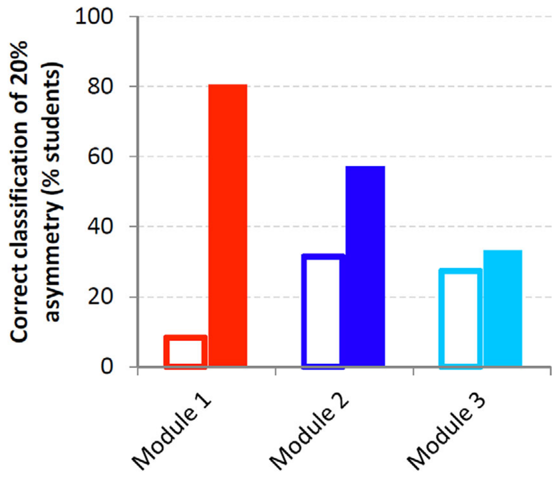

FIGURE 4 Percentage of students correctly classifying a horse presenting with 20% movement asymmetry as lame in the correct limb in the randomised baseline 'warm-up' for Module 1–3 before training (outline) and who successfully passed four successive evaluations at Level 6 (20% asymmetry vs. sound horses) in the game for the respective Module following training (solid)

lameness assessment as 6 (2) out of 10 (0–not difficult, 10–extremely challenging), estimated that they would correctly assess 46% (24%) of cases if they were to spend next week at an equine referral hospital and rated their confidence in their lameness assessment skills as 5 (2) out of 10 (0–not at all confident, 10–very confident). One hundred per cent of students indicated that they needed further training in lameness evaluation skills.

Baseline performance versus learning effect for horses with 20% movement asymmetry (subtle lameness)

There was a significant effect of training on the ability to classify subtle lameness correctly (Figure 4): In Module 1 (forelimb lameness), the percentage of students correctly classifying a horse with 20% movement asymmetry as lame in the correct limb increased from a baseline of 8% to 81% (N = 36), the improvement being significant ($p < 0.001$). In Module 2 (simplified hindlimb lameness), performance increased from 31% to 57% of students (N = 35), the improvement being significant ($p = 0.049$). In Module 3 (realistic hindlimb lameness), there was no significant improvement in the ability to correctly classify 20% movement asymmetry ($p = 0.791$), with 27% of students correctly classifying the lame limb prior to training and 33% after training (N = 33).

Modules 1 to 3 (adaptive staircase learning)

The percentage of students successfully completing a Module (they 'won') was 64% (23 of 36 students) for Module 1, 14% (5 of 36 students) for Module 2 and 6% (2 of 36 students) for Module 3 (Figure 5). The mean (SD) duration for Module completion was 19 (17) minutes for Module 1, 17 (16) minutes for Module 2 and 18 (10) minutes for Module 3. The mean (SD) total number of horses assessed was 61 (18) for Module 1, 70 (22) for Module 2 and 72 (18) for Module 3. The mean (SD) number of steps down to an easier level was 4 (2) for Module 1, 5 (2) for Module 2 and 6 (2) for Module 3.

Module 4 (random presentation)

The median time taken to complete Module 4 was 33 minutes. Across all asymmetry levels (Figure 6), the mean (SD) percentage of sound horses classified correctly as sound was 82% (19%) for horses examined for forelimb lameness and 39% (22%) for horses examined for hindlimb lameness, being significantly different between fore- and hindlimb lameness assessment ($p < 0.001$). The percentage of lame horses classified correctly as generally lame (irrespective of the limb) was 80% (15%) for forelimb lameness and 70% (17%) for hindlimb lameness, being significantly different between fore- and hindlimb lameness assessment ($p = 0.003$). The percentage of lame horses classified correctly as lame with lameness attributed to the correct limb was 65% (12%) for forelimb lameness and 56% (15%) for hindlimb lameness, being significantly different between fore- and hindlimb lameness assessment ($p = 0.003$). There was a significant difference between correctly classifying horses as sound or generally lame for hindlimb lameness ($p < 0.001$), but not for forelimb lameness ($p = 0.631$).

Reasons for erroneous classifications varied in similar proportions between lame horses classed sound, sound horses classed lame and lame horses classed as affected in the incorrect limb (Figure 6). There was a significant difference between fore- and hindlimb lameness in the proportion of errors attributable to sound horses declared lame ($p = 0.006$) and lame horses declared sound ($p = 0.024$), but not for the incorrect selection of the affected limb in a horse correctly classed lame ($p = 0.678$).

At the individual asymmetry level, the mean (SD) percentage of horses correctly identified as lame with lameness attributed to the correct limb decreased from 92% (15%) of horses for forelimb lameness and 85% (20%) for hindlimb lameness at 70% movement asymmetry to 35% (24%) and 38% (21%) of horses, respectively, for 10% movement asymmetry (Figure 7). Chance level was 33%.

The mean (SD) visual detection threshold for the just noticeable difference for asymmetry in general (irrespective of the affected limb) was 13% (5%) movement asymmetry for forelimb lameness. For hindlimb lameness, there were limitations to estimating the detection threshold due to the high frequency of false positives (sound horses declared lame) at a given asymmetry level, which skews the threshold calculation and prohibits fitting a psychometric function. A fit was only possible for six of 32 students, across whom the mean (SD) detection threshold was 13% (6%) asymmetry.

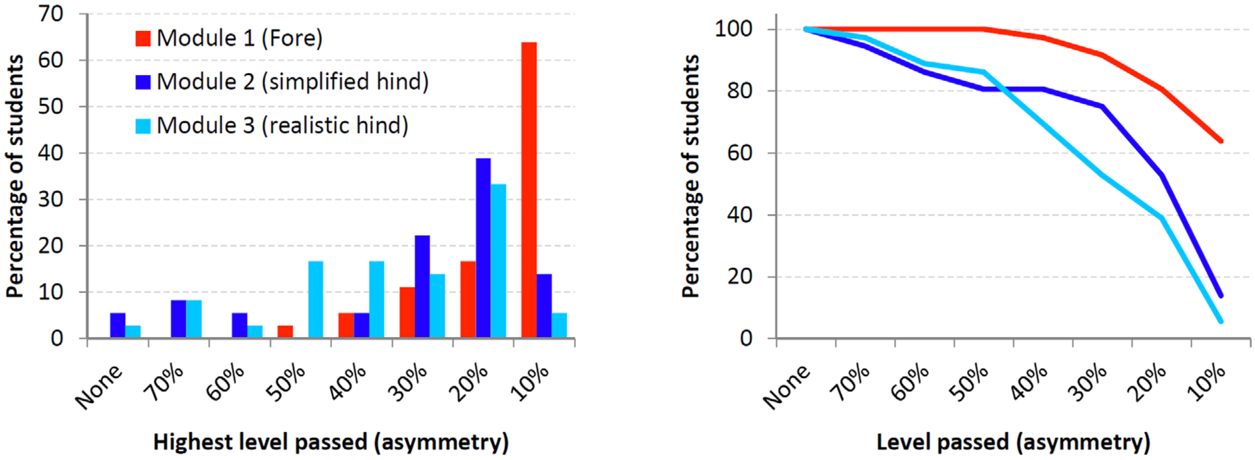

FIGURE 5 Performance for all 36 students for Module 1 (red, forelimb lameness), Module 2 (blue, simplified hindlimb lameness) and Module 3 (turquoise, realistic hindlimb lameness). 'None' – students did not pass the first level successfully. Left: highest level passed, right: cumulative percentage of students passing a given level

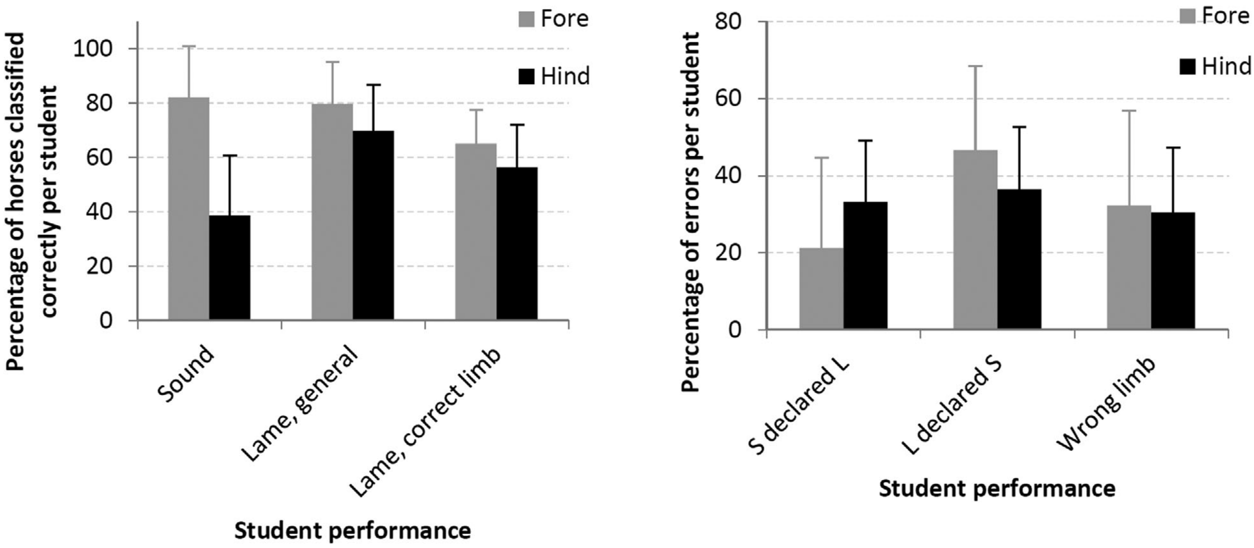

FIGURE 6 Performance and reason for error in Module 4 (random presentation). Error bar: 1 SD. Left: percentage of correct classifications. Grey – horses in front view examined for forelimb lameness, black – horses in rear view examined for hindlimb lameness. Right: percentage of all errors attributed to declaring a sound horse lame ('S declared L'), a lame horse sound ('L declared S') and identifying the incorrect limb as lame ('Wrong limb')

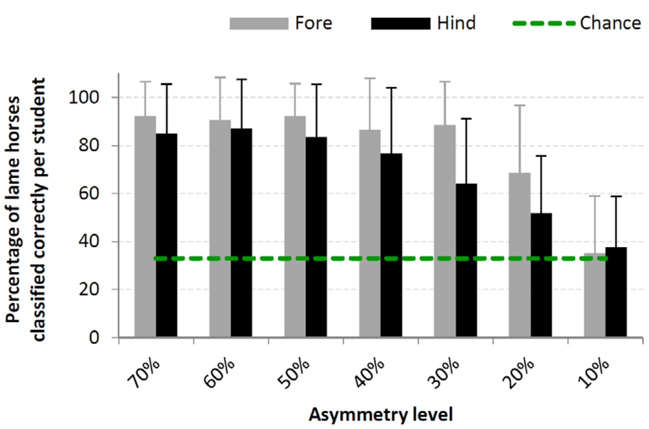

FIGURE 7 Percentage of lame horses classified with lameness in the correct limb for each asymmetry level in Module 4. Grey – horses in front view examined for forelimb lameness, black – horses in rear view examined for hindlimb lameness, dashed green line: chance level. Error bar: 1 SD

Signal detection measures of diagnostic accuracy are summarised in Table 1. Sensitivity and specificity as well as NPV and PPV for an assumed 1:1 ratio of sound and lame horses were significantly different between fore- and hindlimb lameness assessment ($p \leq 0.013$). The effect size was small for sensitivity (mean difference of 4.1%) and large for the remaining metrics (mean difference of 20.4–43.5%).

Questionnaires

A total of 27 of 36 students (75%) completed the questionnaire after training. The average response category for all eight questions relating to learning of visual lameness assessment aspects was 'agree'. A total 93% of students chose 'agree' or 'strongly agree' that they learned to visually examine a lameness, 67% that they improved their ability to differentiate between a sound and a lame horse, 93% that they improved their ability to identify a lame horse, 81% that they improved their ability to correctly detect the lame hindlimb, 93% that they improved their ability to correctly detect the lame forelimb, 59% that they improved their ability to identify a mild lameness, 67% that they improved their confidence in performing a visual lameness examination and 78% that they improved their confidence in determining the correct limb as lame. Students rated enjoyment of the material as 6 (3) out of 10 (0–not at all, 10–very much) and overall quality of the teaching material as 7 (1) out of 10 (0–poor, 10–excellent). A total of 93% of students felt they still needed further training.

Comparing responses before and after training for the 27 students who completed both questionnaires, there was a significant effect of training on how difficult students found lameness assessment ($p = 0.027$, improving from on average 6 to 5 out of 10), the estimated percentage of horses students thought they would assess correctly in practice ($p = 0.032$, improving from on average 48 to 57%) and students' confidence in their ability ($p = 0.013$, improving from on average 4 to 5 out of 10). There was no significant effect ($p \geq 0.227$) on the difficulty rating (0–very simple, 10–very difficult) of identifying a horse as being sound (mean (SD) rating 6 (6) out of 10), identifying a forelimb lameness (mean (SD) rating 3 (4) out of 10) and identifying a hindlimb lameness (mean (SD) rating 6 (6) out of 10). However, ratings were significantly different between the perceived difficulty of fore- and hindlimb lameness ($p < 0.001$).

There was no linear relationship between self-rated task difficulty and performance for forelimb ($p = 0.078$) and hindlimb ($p = 0.507$) lameness assessment. The relationship between general difficulty rating and performance across Module 4 was also not significant ($p = 0.052$), yet a significant effect may be detected with a greater sample size given this p-value. General confidence rating ($p = 0.226$) and estimated percentage of horses assessed correctly at a referral hospital ($p = 0.133$) were not significantly associated. However, there was a strong linear relationship between perceived task difficulty and rater confidence ($p = 0.001$).

DISCUSSION

Summary

This study showed that by engaging in systematic perceptual learning, students were able to recognise and classify fore- and hindlimb lameness in on average 90 minutes. This included the ability to differentiate between normal and lame horses and classification of the correct limb as lame, especially for horses presenting with more noticeable lameness of around 40–70% movement asymmetry. Classification reliability decreased with decreasing lameness severity and was lower for hindlimb lameness than for forelimb lameness. Variation across students illustrated that some individuals may need more training/deliberate practice to achieve the same end result than others. This mirrors other learning curves in the health education space, which typically exhibit significant variation between learners despite common trends.[27] At the same time, students completed the training from different experience levels, which may explain some of the variation. Despite the positive impact of training, discrimination between sound and hindlimb lame horses remained poor, with a large number of sound horses being mistaken for lame. Yet the acquired perceptual skills after training were similar to those of experienced practitioners assessing the same animations and struggling with the same discrimination issues.[20] We therefore consider the skills acquired through the game substantial, especially in light of the short engagement time required. At the same time, we recognise the scope to improve visual detection and discrimination skills further – both for students as well as seasoned practitioners who may fall victim to the same perceptual illusions and limitations. Overall we therefore recommend continued deliberate practice involving feedback to sharpen one's visual skills to a point of high reliability.

Impact of perceptual learning on the ability to correctly classify subtle lameness in Module 1 to 3

For the adaptive staircase learning in Module 1 to Module 3, the results showed a substantial learning effect attributable to engaging in the training. For subtle lameness of 20% movement asymmetry, 80% of students reliably performed a correct classification after training with Module 1 (forelimb lameness), an increase by 72% over baseline performance. This result demonstrated the profound and fast effect perceptual learning can achieve, here after a training session of around 20 minutes on average. Less impact was achieved for hindlimb lameness (Modules 2 and 3), likely due to increasing task complexity, where more learning is required for the same level of sensitivity and specificity. This is not surprising, as increasing 'noise' in a visual stimulus generally makes its detection more difficult, resulting in longer decision times and fewer correct decisions. The warm-up for Module 2 and 3 showed an increase in baseline ability to correctly classify a lame horse with 20% movement asymmetry, tripling from 8% in Module 1 to around 30% in Module 2/3. This may have been caused by skill transfer between modules, since – despite difference in view – students looked for the same feature: asymmetry in vertical movement of a body landmark. At the same time, the increase of false positives and performance around chance level (33%) for baseline assessment in Module 2 and 3 could equally be responsible for this increase, with students potentially guessing. Results suggest that students would need to practise the complex hindlimb lameness movement pattern more often in order to achieve performance comparable to that achieved for forelimb lameness.

Assessment of hindlimb lameness: false positives and poor diagnostic accuracy in Module 4

For the classification of hindlimb lameness, it became apparent that students started to 'see lameness where there was none' (false positives) in Module 4, incorrectly classifying a large proportion of sound horses - 61% on average - as lame. This compared to just 18% of sound horses being mistaken for lame for forelimb lameness assessment. These findings match previous work, reporting an overall 50% of sound horses being mistaken as lame by students assessing videos[22] and 72% of sound horses assessed for hindlimb lameness being mistaken as lame in animations evaluated even by experts compared to 28% for forelimb lameness.[20] Consequently, the likelihood of a horse classified as hindlimb lame truly being lame (PPV) and the likelihood of a horse assessed for hindlimb lameness and classified as sound truly being sound (NPV) was low in this study. Results still compared favourably to the performance of equine practitioners:[20] our trained students achieved a mean PPV of 0.60 compared to 0.53 for veterinarians with a range of expertise levels and NPV of 0.68 compared to 0.59 for veterinarians with a range of expertise levels.[20] Yet this performance level is still uncomfortably close to flipping a coin (0.5).

A possible explanation for the high error rate in hindlimb lameness assessment might be the complexity of the pelvic movement pattern: comparing student performance for simplified and complex hindlimb movement asymmetry in Module 2 and 3 showed that performance dropped with the introduction of pelvic rotation, despite students looking for the same feature within this more complex signal. Therefore, for hindlimb lameness, it is as important to train veterinarians in the correct classification of horses as sound as it is to recognise lame horses. To date, this problem of unreliable soundness 'classification' remains largely unaddressed and requires urgent attention.

Lameness detection ability after training

The average visual asymmetry detection threshold following training was 13%. This figure compares favourably with previous reports of around 25% asymmetry for abstracted hindlimb lameness patterns,[50] 15% asymmetry in simple animations of hindlimb lameness without pelvic rotation[51] and an estimated 15–25% asymmetry for the animations of fore- and hindlimb lame horses assessed by practitioners.[20] It is however important to note that these detection thresholds relate to identifying the presence of asymmetry only. When factoring in the ability to correctly determine the affected limb as well, thresholds are higher: for at least 80% of lame horses during random presentation to be classified as lame with lameness in the correct limb, movement asymmetry of ≥30% was required for forelimb lameness and ≥50% for hindlimb lameness. This matches previous unpublished data (Sandra D. Starke) where horses shown to equine veterinarians in videos required around 50% movement asymmetry for a 50% probability of being classed lame. The just noticeable difference, respectively detection threshold, is hence insufficient to make predictions about diagnostic accuracy. Remarkably, 64% of our students reliably discriminated between 10% asymmetrical and sound horses in Module 1 (forelimb lameness) during adaptive staircase learning. This demonstrates in principle the subtle signals people can learn to detect through perceptual learning, echoing the literature.[28,29,31,32] To what degree these learning effects translate to the live assessment of horses, and how long abilities are retained following training, remains to be studied.

Outlook: What can we expect from more extensive training?

How good would learners get with more training? The literature on visual perception notes a physiological limit beyond which certain low-level discrimination tasks cannot be further improved.[52–55] Very difficult discrimination tasks require excessive practice time and may reach a perceptual limit.[29] Beyond this, continuing to train may produce small incremental improvements, but there are diminishing skill returns. This is in line with the learning curve literature,[56] which encourages the optimisation of learning for the best rate of return.[27] Short training sessions, coarse discrimination and/or multiple stimuli can also aid generalisation of learned pattern recognition.[29] Further, perceptual learning is susceptible to influences such as sleep, feedback, familiarity, signal noise and stimulus awareness.[28,32] All of these factors could be investigated in future to optimise the impact of training on skill. The literature on learning curves highlights the point at which, without deliberate practice, expertise does not improve further, and performance stays at the level of an 'automatic expert' despite further repetitions.[27] Further, without refresh intervals, skills will diminish through forgetting.[57] The importance of forgetting curves,[58] respectively the interaction between learning and forgetting,[59] should hence equally be considered. The optimal practice time, refresh intervals and the generalisation to the assessment of real horses for our training approach remain to be studied.

Recognising the greyzone between soundness and lameness

In the field, there is of course a greyzone area between soundness and lameness. This greyzone may in future benefit from objective gait analysis, should it prove impossible to reliably learn visual skills to discriminate between sound and mildly lame horses, especially for the assessment of hindlimb lameness. Based on the findings of this and previous studies, we recommend allowing for a substantial amount of training time to address the discrimination between sound and hindlimb lame horses, as this skill will take time and practice to develop. Unreliable soundness classification (with regard to the presence or absence of clinically relevant lameness) is particularly important for pre-purchase examinations, as a sound horse declared lame may be significantly de-valued and/or not be sold. Unsurprisingly, unreliable soundness classification is the source of constant discussion among horse owners in relation to the veterinary purchase examination.[60]

To illustrate the dilemma, the majority of horses considered free from lameness by their owner surpass thresholds set by objective gait analysis of around 20% movement asymmetry,[61,62] bearing in mind that no clinical examination was performed, and the clinical status of the horses was unknown. At the same time, subclinical problems of the locomotor system have been estimated to account for 75% of poor performance cases.[63] It is hence important to set the 'criterion' for the discrimination between sound and lame horses correctly, as subtle asymmetry may or may not be associated with pathology. This means that veterinarians have to learn a systematic approach to decision making under uncertainty, where otherwise sound horses may be falsely declared lame, especially for hindlimb lameness.

At present, we do not know whether there is a distinct movement asymmetry threshold differentiating sound from lame horses, that is horses with no clinically significant movement asymmetry from those displaying lameness as a sign of underlying pathology and/or pain. Our results certainly highlight that it is unreasonable to expect practitioners in the field to reliably detect and classify subtle/mild lameness that presents at an asymmetry level of less than around 20–30%, taking into consideration variation in a horse's movement and sub-optimal viewing conditions when assessing real horses under real conditions. Different clinicians might simply recognise or not recognise these very subtle signs based on perceptual limits.

Student feedback on the learning experience

Questionnaires indicated a mainly effective and positive learning experience when engaging with the game: for all eight questions addressing competence and confidence, the majority of students either agreed or strongly agreed. There was a significant improvement in self-evaluation following training with regard to overall difficulty rating of lameness assessment, estimated percentage of horses students thought they would evaluate correctly in the real world and students' confidence in their abilities. Lowest agreement was on the game improving ability to differentiate between sound and lame horses and improving ability to identify a mild lameness, mirroring the quantitative outcome findings. Students rated assessment of hindlimb lameness significantly more difficult (average 6 out of 10) than forelimb lameness (average 3 out of 10), again matching the quantitative outcome findings.

Despite the parallels between questionnaire responses and measured outcomes, there was no significant linear relationship between self-evaluation and actual performance. Importantly, 93% of students felt they needed further training, highlighting that a more comprehensive training programme should be deployed in order to improve skills further. Results map onto the self-evaluation literature, which shows that feedback supports learning and feeds into global self-assessment.[64] One major aim of professional degrees such as veterinary medicine is to develop self-awareness skills and move learners from a position of unconscious incompetence, through to conscious incompetence (i.e. with a knowledge of their own self-limitations), and eventually to conscious and unconscious competence. Identifying lameness evaluation as difficult is therefore an important milestone for many students and it appears that our tool has enabled some students to reach this higher stage of competence.

Generalisation and limitations

The results from this study are expected to generalise to any other cohorts of learners engaging in the LamenessTrainer game. Given the individual differences reported here and in the literature on learning curves,[27,56] reported averages do not reflect all individual learners. Between-participant variation should hence be taken into consideration and individual support structured and provided when educating students through perceptual learning.

This study was based on an opportunistic sample of 3rd year veterinary students who volunteered their time to enhance their learning. This sample may have been self-selected to a degree from students interested in equine careers. This in turn may have resulted in baseline performance slightly better than that which might be expected in a random population sample, given the prior familiarity with horses and in many cases a basic understanding of lameness assessment. Learners fully unfamiliar with horses may hence require slightly more exposure to the game for comparable performance levels.

While this study was able to quantify detection and discrimination skills with high accuracy based on gold standard animations with a definite ground truth, transfer of these skills when assessing real horses remains to be studied. We assume that detection thresholds and performance will worsen in real-life settings due to factors such as stride-to-stride variation, movement of the horses away from/towards the observer, suboptimal lighting conditions and asymmetrical conformation. Transfer of skills acquired here into clinical practice remains to be studied.

CONCLUSION

This study demonstrated that deliberate practice and perceptual learning embedded in a gamified teaching approach are effective for teaching visual detection and discrimination skills in equine lameness. While developed skills were substantial, scope for further improvement remained, and in future it will be of importance to examine achievable performance with more practice, retention and optimal discrimination criteria. The skill transfer to the assessment of real horses in practice remains to be studied, where future evaluations that examine how perceptual skills translate into non-perfect conditions would be of great value. Lameness evaluations entail a vast amount of expertise when establishing the cause of the observed clinical sign of movement asymmetry. Learning to integrate these basic perceptual skills with systematic clinical reasoning approaches will be a critical part of the move from novice to expert.

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AUTHOR CONTRIBUTIONS

Sandra D. Starke, Gregory C. Miles, Sarah B. Channon and Stephen A. May designed the study. Sandra D. Starke created the computer animations, and Gregory C. Miles created the online game. Sandra D. Starke, Gregory C. Miles and Sarah B. Channon collected the data. Sandra D. Starke analysed the data. Sandra D. Starke, Sarah B. Channon and Stephen A. May interpreted the data and wrote the draft manuscript. All authors have edited, read and approved the final manuscript.

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REFERENCES

1. Hu CH, Kundel HL, Nodine CF, Krupinski EA, Toto LC. Searching for bone fractures: a comparison with pulmonary nodule search. Acad Radiol. 1994;1:25–32.
2. Nodine CF, Kundel HL, Mello-Thoms C, Weinstein SP, Orel SG, Sullivan DC, et al. How experience and training influence mammography expertise. Acad Radiol. 1999;6:575–85.
3. Krupinski EA, Tillack AA, Richter L, Henderson JT, Bhattacharyya AK, Scott KM, et al. Eye-movement study and human performance using telepathology virtual slides. Implications for medical education and differences with experience. Hum Pathol. 2006;37:1543–56.
4. Leong JJH, Nicolaou M, Emery RJ, Darzi AW, Yang G-Z. Visual search behaviour in skeletal radiographs: a cross-speciality study. Clin Radiol. 2007;62:1069–77.
5. Kok EM, De Bruin ABH, Robben SGF, Van Merriënboer JJG. Learning radiological appearances of diseases: does comparison help? Learn Instr. 2013;23:90–7.
6. Brunnekreef JJ, Van Uden CJt, Van Moorsel S, Kooloos JG. Reliability of videotaped observational gait analysis in patients with orthopedic impairments. BMC Musculoskelet Disord. 2005;6:17.
7. Wren TAL, Gorton GE, Õunpuu S, Tucker CA. Efficacy of clinical gait analysis: a systematic review. Gait Posture. 2011;34:149–53.
8. Keegan KG, Wilson DA, Wilson DJ, Smith B, Gaughan EM, Pleasant RS, et al. Evaluation of mild lameness in horses trotting on a treadmill by clinicians and interns or residents and correlation of their assessments with kinematic gait analysis. Am J Vet Res. 1998;59:1370–7.
9. Peham C, Licka T, Girtler D, Scheidl M. Supporting forelimb lameness: clinical judgement vs. computerised symmetry measurement. Equine Vet J. 1999;31:417–21.
10. Main DCJ, Clegg J, Spatz A, Green LE. Repeatability of a lameness scoring system for finishing pigs. Vet Rec. 2000;147:574–6.
11. Mackey AH, Lobb GL, Walt SE, Stott NS. Reliability and validity of the Observational Gait Scale in children with spastic diplegia. Dev Med Child Neurol. 2003;45:4–11.
12. Weishaupt MA. Adaptation Strategies of Horses with Lameness. Vet Clin North Am Equine Pract. 2008;24:79–100.
13. Keegan KG. Evidence-based lameness detection and quantification. Vet Clin North Am Equine Pract. 2007;23:403–23.
14. Dyson PK, Jackson BF, Pfeiffer DU, Price JS. Days lost from training by two- and three-year-old Thoroughbred horses: a survey of seven UK training yards. Equine Vet J. 2008;40:650–7.
15. Egenvall A, Lönnell C, Roepstorff L. Analysis of morbidity and mortality data in riding school horses, with special regard to locomotor problems. Prev Vet Med. 2009;88:193–204.
16. Blue Cross. National Equine Health Survey (NEHS). 2016. https://www.bluecross.org.uk/sites/default/files/downloads/NEHS%20results%202016%2022%20Sept%202016.pdf. Accessed 10 February 2021.
17. Blue Cross. National Equine Health Survey. 2018. https://www.bluecross.org.uk/sites/default/files/downloads/NEHS-results-2018.pdf. Accessed 10 February 2021.
18. Keegan KG, Dent EV, Wilson DA, Janicek J, Kramer J, Lacarrubba A, et al. Repeatability of subjective evaluation of lameness in horses. Equine Vet J. 2010;42:92–7.
19. Mccracken MJ, Kramer J, Keegan KG, Lopes M, Wilson DA, Reed SK, et al. Comparison of an inertial sensor system of lameness quantification with subjective lameness evaluation. Equine Vet J. 2012;44:652–6.
20. Starke SD, Oosterlinck M. Reliability of equine visual lameness classification as a function of expertise, lameness severity and rater confidence. Vet Rec. 2019;184:63.
21. Kramer J, Keegan KG. 12 - kinematics of lameness. In: Hinchcliff KW, Kaneps AJ, Geor RJ, editors. Equine sports medicine and surgery. 2nd ed. London: W.B. Saunders; 2014.
22. Starke SD, May SA. Veterinary student competence in equine lameness recognition and assessment: a mixed methods study. Vet Rec. 2017;181:168.
23. Buchner HHF, Savelberg HHCM, Schamhardt HC, Barneveld A Head and trunk movement adaptations in horses with experimentally induced fore- or hindlimb lameness. Equine Vet J. 1996;28:71–6.
24. Buchner HHF, Savelberg HHCM, Schamhardt HC, Barneveld A. Limb movement adaptations in horses with experimentally induced fore- or hindlimb lameness. Equine Vet J. 1996;28:63–70.
25. Ericsson KA, Charness N. Expert performance - its structure and acquisition. Am Psychol. 1994;49:725–47.
26. Ericsson KA, Krampe RT, Tesch-Römer C. The role of deliberate practice in the acquisition of expert performance. Psychol Rev. 1993;100:363–406.

27. Pusic MV, Boutis K, Hatala R, Cook DA. Learning curves in health professions education. Acad Med. 2015;90:1034–42.
28. Kellman PJ, Garrigan P. Perceptual learning and human expertise. Phys Life Rev. 2009;6:53–84.
29. Sagi D. Perceptual learning in Vision Research. Vision Res. 2011;51:1552–66.
30. Fahle M. Introduction. In: Fahle M, Poggio T, editors. Perceptual learning. London: Bradford / The MIT Press; 2002.
31. Goldstone RL. Perceptual learning. Annu Rev Psychol. 1998;49:585–612.
32. Fine I, Jacobs RA. Comparing perceptual learning across tasks: a review. J Vis. 2002;2:190–203.
33. Baxter GM. Adams and Stashak's lameness in horses. Chichester, West Sussex; Ames, Iowa: John Wiley & Sons; 2020.
34. Wyn-Jones G. The diagnosis of the causes of lameness. In: Wyn-Jones G, editor. Equine lameness. Oxford: Blackwell Scientific Publications; 1988.
35. Ross MW, Dyson SJ. Diagnosis and management of lameness in horses. 2nd ed. St. Louis, Missouri: Elsevier Saunders; 2011.
36. Stashak TS. Adams' lameness in horses. Chichester, West Sussex; Ames, Iowa: Wiley-Blackwell; 2002.
37. Wood D, Bruner JS, Ross G. The role of tutoring in problem solving. J Child Psychol Psychiatry. 1976;17:89–100.
38. Simons KD, Klein JD. The impact of scaffolding and student achievement levels in a problem-based learning environment. Instr Sci. 2007;35:41–72.
39. Buchner HH. Gait adaptation in lameness. In: Back W, Clayton HM, editors. Equine locomotion. London: Saunders; 2001.
40. Peham C, Scheidl M, Licka T. A method of signal processing in motion analysis of the trotting horse. J Biomech. 1996;29:1111–4.
41. Peham C, Licka T, Girtler D, Scheidl M. Hindlimb lameness: clinical judgement versus computerised symmetry measurement. Vet Rec. 2001;148:750–2.
42. May SA, Wyn-Jones G. Identification of hindleg lameness. Equine Vet J. 1987;19:185–8.
43. Back W, Barneveld A, Van Weeren PR, Van Den Bogert AJ. Kinematic gait analysis in equine carpal lameness. Acta Anat (Basel). 1993;146:86–9.
44. Clayton HM. Cinematographic analysis of the gait of lame horses. J Equine Vet Sci. 1986;6:70–8.
45. Audigié F, Pourcelot P, Degueurce C, Geiger D, Denoix JM. Fourier analysis of trunk displacements: a method to identify the lame limb in trotting horses. J Biomech. 2002;35:1173–82.
46. Reed SK, Kramer J, Thombs L, Pitts JB, Wilson DA, Keegan KG. Comparison of results for body-mounted inertial sensor assessment with final lameness determination in 1,224 equids. J Am Vet Med Assoc. 2020;256:590–9.
47. Macmillian NA, Creelman CD. Detection theory. A user's guide. 2nd ed. New York; London: Psychology Press; 2008.
48. Starke SD, May SA, Pfau T. Understanding hind limb lameness signs in horses using simple rigid body mechanics. J Biomech. 2015;48:3323–31.
49. Faber M, Johnston C, Schamhardt H, Weeren RV, Roepstorff L, Barneveld Ab Basic three-dimensional kinematics of the vertebral column of horses trotting on a treadmill. Am J Vet Res. 2001;62:757–64.
50. Parkes RSV, Weller R, Groth AM, May S, Pfau T. Evidence of the development of 'domain-restricted' expertise in the recognition of asymmetric motion characteristics of hindlimb lameness in the horse. Equine Vet J. 2009;41:112–7.
51. Starke S, Pfau T, May S. Asymmetry detection thresholds in novices assessing dynamic stimuli. Perception. 2014;43:478.
52. Dorais A, Sagi D. Contrast masking effects change with practice. Vision Res. 1997;37:1725–33.
53. Adini Y, Sagi D, Tsodyks M. Context-enabled learning in the human visual system. Nature. 2002;415:790–3.
54. Mayer MJ. Practice improves adults' sensitivity to diagonals. Vision Res. 1983;23:547–50.
55. Westheimer G. Is peripheral visual acuity susceptible to perceptual learning in the adult? Vision Res. 2001;41:47–52.
56. Anzanello MJ, Fogliatto FS. Learning curve models and applications: literature review and research directions. Int J Ind Ergon. 2011;41:573–83.
57. Jaber MY, Kher HV. Variant versus invariant time to total forgetting: the learn–forget curve model revisited. Comput Ind Eng. 2004;46:697–705.
58. Loftus GR. Evaluating forgetting curves. J Exp Psychol Learn Mem Cogn. 1985;11:397–406.
59. Anderson JR, Fincham JM, Douglass S. Practice and retention: a unifying analysis. J Exp Psychol Learn Mem Cogn. 1999;25:1120–36.
60. Belasik P. Asymmetry and soundness: analysis and selling horses. 2018. https://paulbelasik.com/index.php/asymmetry-and-soundness-the-pre-purchase-exam-and-trying-tomake-money-selling-horses/. 2018. Accessed 10 February 2021
61. Rhodin M, Egenvall A, Andersen PH, Pfau T. Head and pelvic movement asymmetries at trot in riding horses perceived as sound by their owner. Equine Vet J. 2015;47:10–1.
62. Rhodin M, Egenvall A, Haubro Andersen P, Pfau T. Head and pelvic movement asymmetries at trot in riding horses in training and perceived as free from lameness by the owner. PLoS One. 2017;12:e0176253.
63. Morris EA, Seeherman HJ. Clinical evaluation of poor performance in the racehorse: the results of 275 evaluations. Equine Vet J. 1991;23:169–74.
64. Eva KW, Regehr G. Exploring the divergence between self-assessment and self-monitoring. Adv Health Sci Educ. 2011;16:311–29.

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