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Original Research

Unravelling the speed-going relationship: A proof of concept study from British turf flat and jump race meetings

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ABSTRACT

The maximum galloping speeds of racehorses during a race are influenced by the functional performance of the ground ('going') amongst other factors. For turf racecourses in Britain, the ground is descriptively classified and numerically quantified on the morning of a race meeting by the clerk of the course and subsequently published to assist decision making. Importantly, this includes deciding whether a horse should or should not run. The going is also assessed and classified during the meeting by racing analysts using the normalized winning times from each race result. Differences between going assessments are regularly reported, therefore this study aimed to evaluate whether an alternative method of measuring going could better predict going measured from performances. Measurement and performance data from 25 flat and 25 jump meetings were compared using linear and nonlinear regression models. A continuous two-phase polynomial model for cushioning was found to be the best predictor of performance going for all 50 meetings (adjusted r^2=0.819, P<0.001). As cushioning can provide a going related indicator of the forces that the horse will experience at gallop, this measurement may be useful when evaluating racecourse going. This initial model suggests that there is little performance advantage at maximal galloping speeds above a cushioning value of approximately10 kN, possibly due to changes in limb contact timings to manage limb forces limits as the ground becomes firmer. An expansion of objective measurements of going that relate to performance across a wider geographic region, if not internationally are needed to confirm this limit.

1. Introduction

Going is a term used in horse racing to describe the functional performance of the ground at a racecourse. On turf racecourses, going is influenced by the soil profile, condition, geometry and topography of the track, moisture content, drainage, quality of the grass sward and root structure, amount of use, maintenance and preparation methods and equipment, and local environmental conditions [1–5]. Going assessments are crucial for racecourses [5] and are routinely used to categorize the racing surface conditions. In Britain, a going index value measured with a GoingStick [6,7] and a classification description between firm and heavy are published by clerks of the courses prior to racing.

The stakeholder's interpretation of the published going assessment is important and can dictate whether a horse should or should not run that day. However, an inherent problem with this assessment is that the going index value does not consistently match the classification description [2]. The going index value combines a measure of force necessary to push the GoingStick into the ground (penetration resistance) followed by the force needed to pull it back to 45° (shear resistance) [8] and is influenced by rate of penetration and shear force applied by the operator [9]. This quantitative going index value is used to support the official going assessment but this is not bound by metrics and is a qualitative descriptor of the track presented by racing officials [2]. Additionally, the going assessment may be modified during the day due to feedback from jockeys.

Going is also assessed by horse performance analysts during race meetings by evaluating the influence of the ground on the speed of

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winning racehorses, whilst making allowances for the multitude of other factors that would influence the winning time of each individual race [10]. The speed of a racehorse, and its ability to sustain that speed through stamina, is a multifaceted characteristic influenced by a complex interplay of genetic, biomechanical, tactical and environmental factors [11–16]. A lower moisture content on turf racecourses can support higher speeds [4] and firmer ground is reported to result in higher maximal speeds [17], but horses may be at increased risk of injury [18]. It follows that going can be deduced from horse speeds, provided that specific horse and race related factors are accounted for.

The going measurements described in a recent protocol that was developed for quantifying eventing cross country turf [19] linked rider perception to surface functional properties that relate to the horse [19, 20]. The protocol identified cushioning, which indicates the amount of vertical force that the ground will support, as a key going measurement. Using the same protocol and measurements and linking these to racing performance may enhance the current methods of measuring racing going in Britain. This proof-of-concept study was therefore designed to compare official going measurements and measurements collected from a Vienna Surface Tester (VST) and moisture meter [19], with semi quantitative industry expert normalized race times.

The aim was to identify the strongest relationships between equipment measurements of going, and semi quantitative normalized race-time measurements of going (adjusted for measurable factors that might have affected them so that they were directly comparable) from flat and jump race meetings. A flat and jump meeting model will be developed from one racecourse each initially, followed by inclusion of data from other racecourses, and an overall model of all meetings. Based on the findings of previous studies [8,19,20] it was hypothesized that cushioning would be identified as a strong predictor of performance [19, 20].

2. Materials and methods

2.1. Permissions

Racecourses involved in the study gave permission to collect measurements using the surface tester (VST) and moisture meter on the morning of each race meeting during the time that the clerk of the course took official going measurements and provided informed consent to use the data for this study. Data used to develop the performance measurements were available in the public domain prior to the commencement of the study.

2.2. Racecourses

Eight racecourses took part in this study based in South and South-West England and visits were made over a 2-year period between Spring 2021 and Spring 2023. Data from 25 flat meetings (10 meetings from one racecourse and five meetings from three racecourses) and 25 jump meetings (10 meetings from one racecourse, five meetings from two racecourses, three meetings from one racecourse and two meetings from one racecourse) were analyzed. In total 175 flat races and 182 jump races were included in the analysis. Out of the eight racecourses that took part, one racecourse included five flat meetings and two jump meetings. All seven other racecourses provided either flat or jump data but not both.

2.3. Equipment measurements

The racing line (which is approximately 2 m off the inside running rail) was measured at each racecourse at 250 m intervals using the surface tester VST (Veterinary University Vienna, Vienna, Austria) and moisture meter HH2 (Delta-T Devices Ltd., Cambridge, UK), based on [19]. The surface tester was dropped from incrementally increasing heights up to approximately 1 m at each location, from which cushioning (kN), firmness (g), depth (mm), energy return (%), and top and lower-level stiffness (kN/m) were calculated. Moisture was measured at the same location taking the average of five repeats in close proximity. Each location was recorded from the global positioning sensor within the surface tester. Course mean values and standard deviations were calculated for each variable. The coefficient of variation (%COV) for each variable was then determined (standard deviation/mean*100). Course variability was then calculated as the ensemble mean %COV from all of the variables' %COV [19] in Excel v2304 (Microsoft Corp., Overlake, Redmond, WA, USA).

GoingStick indices were measured and made publicly available by the racecourse on the morning of the race meeting. The corresponding descriptions of going related to average course GoingStick index values from 2008 to 2013 values for flat and jump racing were defined in [21] as a guide. Published values were recorded in the course measurement datasheet in Excel.

2.4. Performance measurements

Performance measurements were estimated independently by SR (author) in a custom spreadsheet [22] based on industry standard methods [10]. Data related to each race were obtained initially, as specified in Table 1 in order that a normalized winning time (time-based going allowance) could be calculated for each race meeting to provide a performance-based measurement of going. The process is described in detail below.

An overall time recorded by a horse will have been affected by several significant factors, not least the course and distance at which the race it contested was run, including that course's topography and conformation. "Standard times" were established for the courses and distances in question, reflecting the time that a horse of given merit, carrying a given weight (or weight-for-age equivalent) could be expected to run in a true run race on neutral ground, the initial times of winners being normalised for those factors. The winning time recorded was noted, along with details of amendments to the overall race distance (which affect the standard time accordingly), and the difference between that recorded time and the standard time was converted into

Table 1
Statistics obtained from the race meetings that were used to estimate the time-based going allowance for each race meeting.

Specific Statistics	Variables	Reason
Race	Distance Race specific change in distance Standard time Race specific change in standard time Number on card Time of the race	Winning time normalized in relation to racecourse and race distance. Number on the card and time of the race provide additional meeting information.
Horse	Ability Weight carried Weight for age allowance	Winning time normalized in relation to the horse's ability and weight carried compared to maturity.
Performance	Winning time Sectional times Finishing speed %	Winning time is used as the basis for determining a performance-related measurement of the going. Sectionals and finishing speed %s are used to determine whether the race was true run or not.
Environmental	Rainfall effect Wind effect (flat only)*	Winning time normalized to the changes in environmental conditions during the race meeting.

* Due to the orientation and length of racecourses, wind may affect flat times in just one direction, with a significant impact on those times, but it will affect jumps times multi-dimensionally with positive and negative impacts cancelling each other to a large degree.

pounds.

This converted winning time was then normalised for weight carried, weight-for-age and the rating the horse appears to have run to (all expressed in pounds (lbs)). Carrying more weight will slow a horse down, all other things being equal, younger horses will run slower than older ones up to a point, again all other things being equal, and more highly rated/athletically talented horses are, by definition, capable of running faster overall times than less talented ones [10–16]. This effectively produces a going allowance for each individual race at each meeting in question, without any knowledge of whether or not the race was true run. If the race were true run, the overall time recorded is likely to reflect closely the ability of the horse that recorded it and the implied speed of the surface on which it took place.

Due to the increased likelihood of a race not being true run (a race that is slower than it is expected to be under given conditions) at longer compared to shorter distances, race-time data will be skewed rather than normally distributed. To establish whether the race was true run percentiles of these normalised winning times were saved and used to inform the expected frequency of true run races [23]. Sectional times were also used to further evaluate whether each race was true run. This was carried out by converting the speed towards the end of a race into a percentage of the average speed for the race overall. "Par" finishing speeds, which are specific to different courses and distances, were also derived from the sectional times that give rise to "fast" overall times and indicate efficient pacing [24,25]. These combined approaches enabled a going allowance to be identified from all the races analysed on a given card, which was the minimum value from all races at that meeting. The lowest value for the meeting implies the most true run race and is indicative of the speed of the racing surface. So, the lower the time-based going allowance, the faster the surface. The approaches described here are considered to be valid within the British Horseracing industry [10, 23–25].

Detailed wind and rainfall information were estimated by an independent analyst to assess weather effects (converted to lbs) for each race on the card where applicable using data from [26]. Their effects were estimated and incorporated into the time-based going allowance calculations. As no official weather station records at the precise location and time at which races took place were available, a degree of uncertainty was involved these calculations. That is, wind and rainfall will undoubtedly have had an effect on race times, but it was not possible to know precisely what that will have been in any given instance, hence the need for sensible estimation.

Wind effects were estimated from wind direction and wind strength, with the effect of the latter being exponential (unpublished data). For wind effects, the time-based going allowance was adjusted according to the geometry of the running line for that race. The range of values for wind strength in the dataset was from 2.0 mph to 17.7 mph for flat race meetings. The direction of wind either sped up or slowed down the times according to whether there was predominantly a headwind, a tailwind, a cross wind, or some combination of all three. The estimated wind effect on performance ranged from -7 lbs (faster times) to +11 lbs (slower times).

Wind is a temporary feature, but rainfall has a cumulative and enduring effect. Rain effects can slow a surface by 20 lb or more in an hour (unpublished industry statistics), in the event of persistent and heavy rain, but are usually much smaller in scale. For rain effects, the time-based going allowance was adjusted relative to the cumulative amount of rainfall/hour in the preceding hours before the race where applicable. Recorded rainfall in the previous hour ranged from zero to 0.5 mm on the flat, and its cumulative effect on race times was estimated at a maximum of 10 lbs over the course of a race meeting. For jump racing, recorded rainfall ranged from zero to 2.1 mm in the previous hour. The estimated effect of this on race times was as much as 89 lbs for one race meeting where "heavy rain" of as much as 1.9 mm/hour occurred for the majority of the race meeting.

2.5. Statistical analysis

Overall going measurement for equipment and time-based going allowance measurements from the first race on the race card for each meeting, along with the meeting details, were collated in Excel v2304 (Microsoft Corp., Overlake, Redmond, WA, USA). Flat and jump meetings were initially analyzed separately, so two separate datasets were collated from all measurements in SPSS v28.0 (SPSS Inc., Chicago, IL, USA) for further analysis. Regression models were developed for each dataset, initially based on 10 meetings from one racecourse, which were then tested by re-modelling the data using 25 meetings from four flat and five jump courses. Finally, both datasets were combined to develop an overall model.

Linear and non-linear (logarithmic, quadratic and exponential) regression models were developed to explore the relationship between the outcome variable (time-based going allowance) and going measurements from the equipment (moisture (%), cushioning (kN), firmness (g), depth (mm), energy return (%), stiffness (kN/m)). The strongest going measurement predictors (largest adjusted r^2) were identified from the initial analysis of 10 meetings at one racecourse, from the 25 meetings at four and five courses and the overall dataset separately. For each dataset, additional transformed measurements were calculated corresponding to each measurement's strongest univariable model. All variables and transformed variables were then inputted into a multivariable stepwise regression to identify and confirm going measurements and transformed measurements from equipment that predicted time-based going allowances for flat, jump and all meetings. The assumption of independent errors and collinearity diagnostics were investigated using the Durbin-Watson test and Variance Inflation Factor (VIF) respectively [27]. Finally, the model was further refined for all meetings to find a best fit using a spline fitting approach to identify the position of a knot in a two-phase continuous polynomial model. All statistical analyses were performed in SPSS v28.0 (SPSS Inc., Chicago, IL, USA) with significance set at $P<0.05$.

3. Results

The race meetings included in the analysis spanned the range of official going that is found on British turf racecourses for both flat and jump racing, but with fewer meetings at the extremes of going, see Fig. 1. For this study, official going classification was grouped by the first description and the bracketed or additional 'in places' descriptions were excluded. For example, good (good to soft in places) was grouped as good. Please see [21] for further information.

The minimum time-based going allowance at each meeting included both true run (flat n=11, jump n=12) and not true run (flat n=11, jump n=13) races. Sectional times were not available for three flat meetings, so it was not possible to determine whether the races at these meeting were true run. Rainfall influenced the time-based going allowance at n=2 (0.1 to 0.5 mm/hr) flat and n=8 (0.1 to 2.1 mm/hr) jump meetings and wind affected n=19 (0.9 to 7.9 m s^{-1}) flat meetings.

For three flat meetings the time-based going allowance was 65±14 lbs (mean ± standard deviation) for shorter distance races (< 8 furlongs) compared to 86±5 lbs for longer distance races (> 8 furlongs). In the regression analysis, the minimum time-based going allowance from the longer distance races were used, as the equipment measurements were taken at locations that followed the racing line (i.e. approximately 2 m off the inside running rail). For the shorter distance races which were run over a straight section of the course, the full width of the track may have been used by the horses and the full width of the track was not measured by the equipment.

Course variability, determined from the ensemble mean %COV of moisture (%), cushioning (kN), firmness (g), depth (mm), energy return (%), and top and lower-level stiffness (kN/m) [19] ranged from 3.3 to 13.9% for flat race meetings and from 6.0 to 12.8% for jump race meetings.

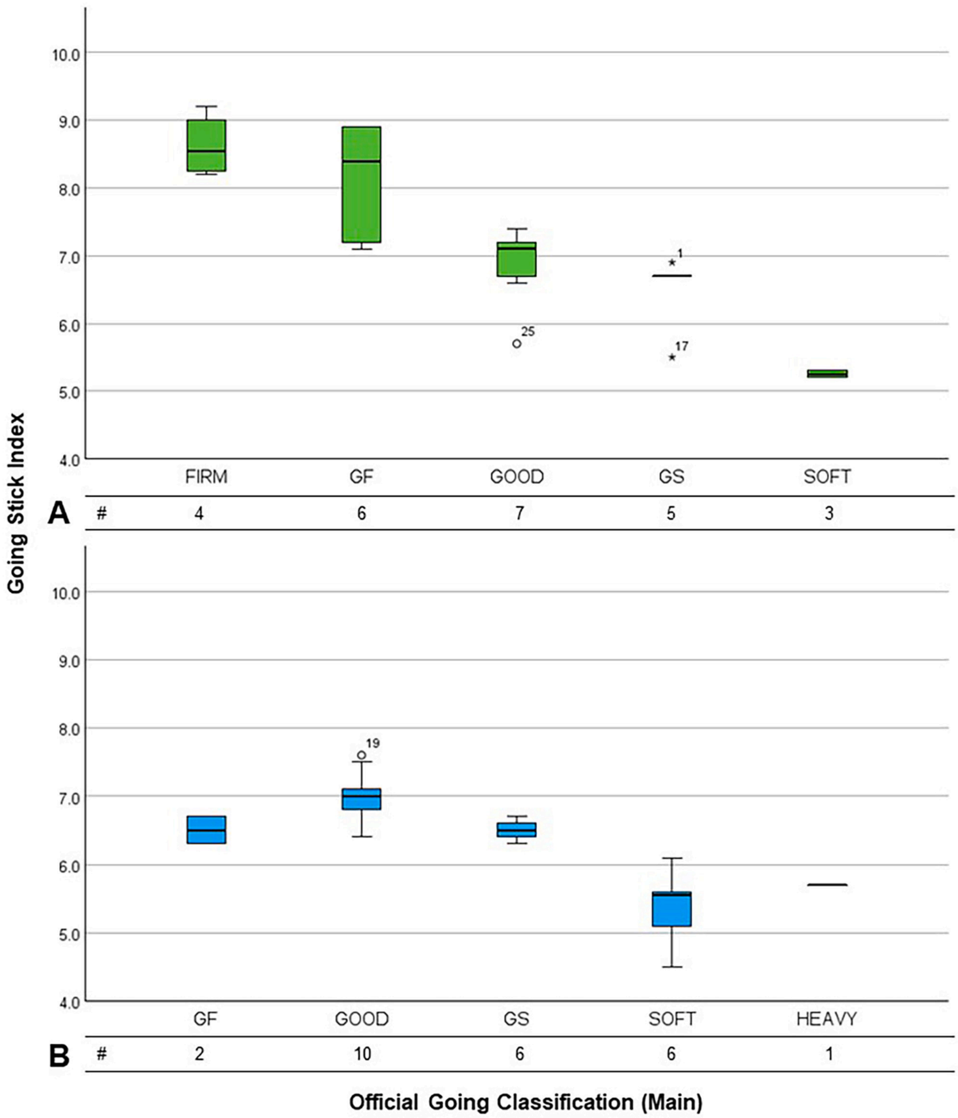

Fig. 1. Range of going and number (#) of A) flat and B) jump race meetings within the dataset and corresponding going index value. Race meetings with outlier going index values are identified with the corresponding race meeting number on each graph. Good to firm (GF), good to soft (GS). (Main) official going classification is grouped by the first official description, excluding bracketed or additional 'in places' descriptions. For example, good (good to soft in places) is grouped as good.

3.1. Flat Racing

Results from linear and non-linear modelling are shown in Tables S1 (one racecourse) and S2 (four racecourses). The strongest predictor of time-based going allowance for the one-course analysis was a quadratic model of cushioning ($r^2 = 0.914$, $P<0.001$). The strongest predictor of time-based going allowance for the four-course analysis was a quadratic model of firmness ($r^2 = 0.726$, $P<0.001$). The results from both analyses are plotted in Fig. 2.

Multivariable stepwise regression identified two going measurements that could significantly ($P<0.05$) predict the performance going. The first and second order components of cushioning predicted 71% of the time-based going allowance (Table 2). The Durbin-Watson statistic was 2.051, indicating that independent errors were not evident in the model. However, VIF values indicated high collinearity between predictor and excluded variables, indicating that firmness and lower-level stiffness could also have predicted the outcome (excluded variables VIF=1.013 – 20.92).

3.2. Jump Racing (chase course where chase/hurdle specified)

Results from linear and non-linear modelling are shown in Table S3 (one racecourse) and Table S4 (five racecourses). The strongest predictor of time-based going allowance for the one-course analysis was a logarithmic model of depth ($r^2 = 0.829$, $P<0.001$). The strongest predictor of time-based going allowance for the five-course analysis was a logarithmic model of cushioning ($r^2 = 0.502$, $P<0.001$). The results from both analyses are plotted in Fig. 3.

Multivariable stepwise regression identified one going measurements that could significantly ($P<0.05$) predict the performance going. The natural log of cushioning predicted 50% of the time-based going allowance (Table 2). The Durbin-Watson statistic was 1.352, indicating that independent errors may not be evident in the model. VIF values indicated high collinearity between predictor and excluded variables, indicating that cushioning could also have predicted the outcome (excluded variables VIF=1.197 – 2537.53).

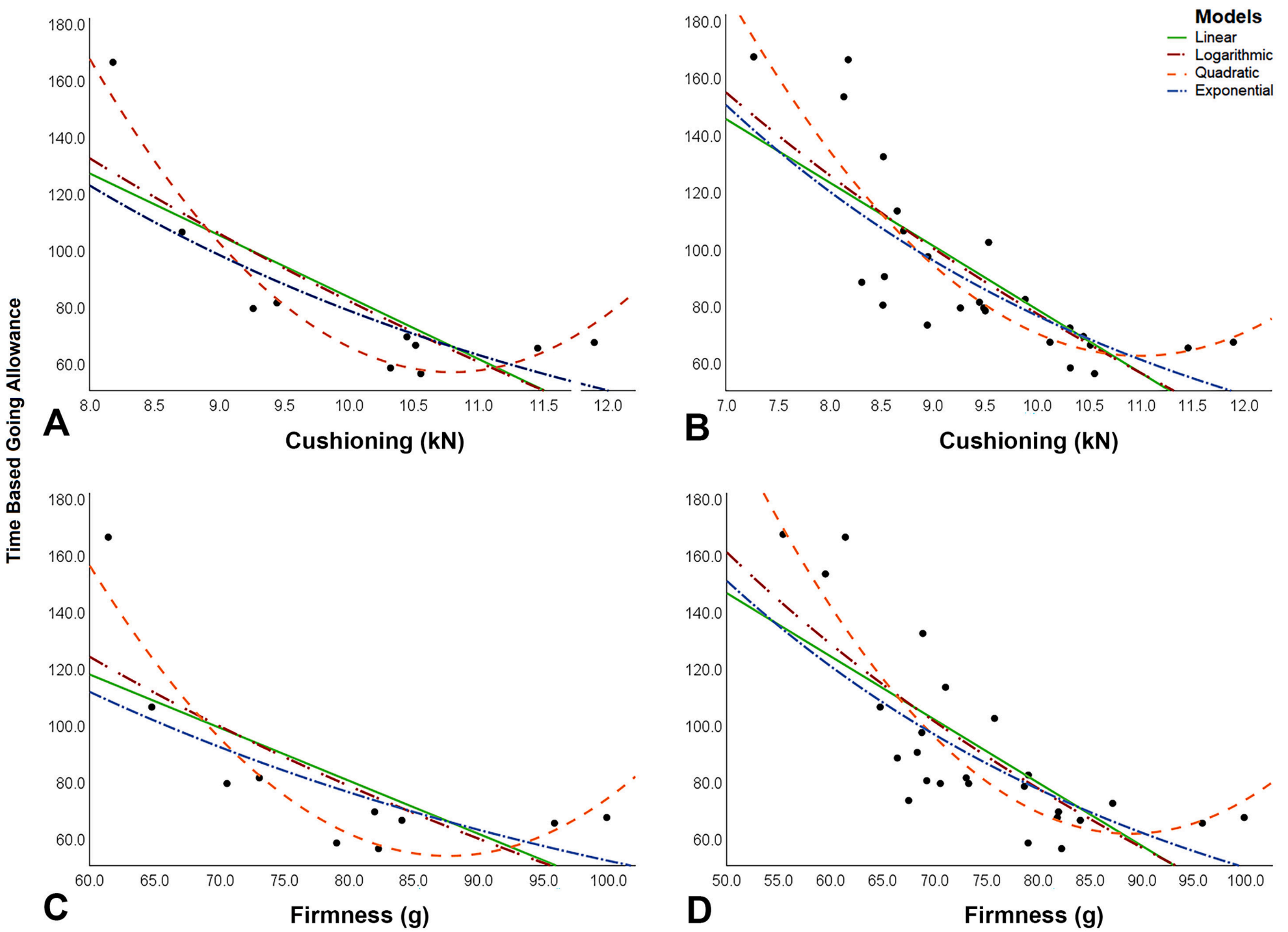

Fig. 2. Linear and non-linear models between time-based going allowance and the two strongest predictor measurements, A and B cushioning (kN) and C and D firmness (g). A and C 10 flat meetings from one racecourse, B and D from four racecourses (10 flat meetings from one racecourse and five flat meetings from three racecourses).

Table 2
Results of stepwise linear regression to predict the time-based going allowance for flat meetings, jump meetings and all meetings including Beta Coefficients and 95% confidence intervals (CI). Significance is denoted as * $P<0.05$, ** $P<0.001$. Durbin Watson Statistic (DWS), where <1 and >3 indicate lack of independence between adjacent residuals.

Meetings	Predictors	Adjusted r^2	Beta Coefficient	95% CI		P	DWS
				Lower	Upper		
Flat	Cushioning	0.572	-22.238	-30.238	-14.238	<0.001	
	Constant		300.871	225.032	376.710		
	Cushioning	0.572	-176.549	-271.747	-81.350	<0.001	2.051
	Cushioning Squared	0.705	8.033	3.089	12.976		
	Constant		1032.282	577.752	1486.813		
Jump	Ln Cushioning	0.502	-556.799	-786.404	-327.194	<0.001	1.352
	Constant		1330.814	857.658	1803.971		
All	Cushioning	0.697	-42.578	-50.600	-34.555	<0.001	
	Constant		505.300	435.428	575.172		
	Cushioning	0.697	-292.082	-382.656	-201.508	<0.001	1.335
	Cushioning Squared	0.813	13.552	8.644	18.459		
	Constant		1632.300	1220.498	2044.103		

3.3. All Race Meetings

Results from linear and non-linear modelling are shown in Table S5 for all fifty race meetings. The strongest predictor of time-based going allowance was a quadratic model of firmness ($r^2 = 0.816$, $P<0.001$), followed closely by cushioning ($r^2 = 0.813$, $P<0.001$).

Multivariable stepwise regression identified two going measurements that could significantly ($P<0.05$) predict the performance going. The first and second order components of cushioning predicted 81% of the time-based going allowance (Table 2). The Durbin-Watson statistic was 1.335, indicating that independent errors may not be evident in the model. However, VIF values indicated high collinearity between predictor and excluded variables, indicating that the first and second order components of firmness and lower-level stiffness and top-

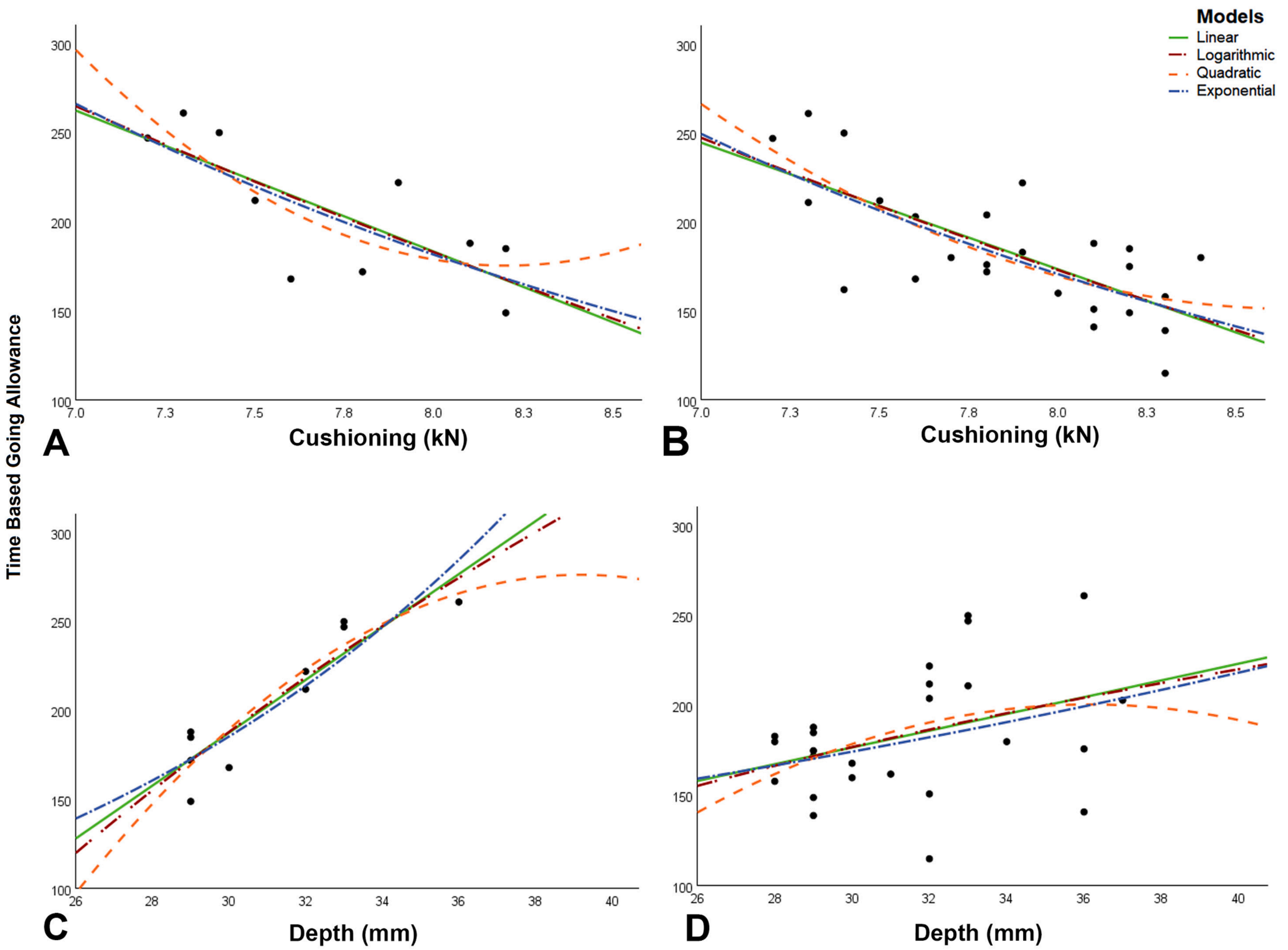

Fig. 3. Linear and non-linear models between time-based going allowance and the two strongest predictor measurements, A and B cushioning (kN) and C and D depth (mm). A and C 10 jump meetings from one racecourse, B and D 25 jump meetings from five racecourses.

level stiffness could also have predicted the outcome (excluded variables VIF=1.009 – 31.861).

An improved continuous two-phase polynomial model for cushioning was identified with a knot at 9.78 kN. Using this model cushioning predicted 82% of the time-based going allowance (adjusted r^2=0.819, P<0.001). Mean ± standard deviation for the second polynomial predicted time-based going allowance (n=8) were 65 ± 1.7, suggesting a plateau in performance above the knot. Both the single and two-phase models are illustrated together with the data from all fifty meetings in Fig. 4.

4. Discussion

In this study the strongest relationships between equipment measurements and winning race time measurements of going were modelled for flat and jump meetings using one, several and all racecourses' models. The main findings of this study were that cushioning, which is a combined measure of firmness, moisture and energy return [19] was found to be a strong predictor of the time-based going allowance for flat and jump racing. As such, our hypothesis could be accepted.

Any tool that is used to quantify and/or classify going must produce data that is relevant to the performance of the horse, and this study indicated that the ability of the tool to measure cushioning may be important, as the measurement indicates the amount of vertical force that the ground will support. When galloping, although powerful hindlimb extensor muscles produce net propulsive forces to accelerate the body forward [28,29], whilst net braking force is produced by the forelimbs which slows and lifts the body into each flight phase [30], maintaining speed is heavily reliant on the ability of the ground to produce vertical reaction forces that support the up-down motion of the body. Vertical ground reaction forces are reported to be in the order of magnitude of approximately 10 kN or twice the body weight of a 500 kg horse during gallop, with the forelimbs experiencing larger vertical forces at slower galloping speeds [31]. At faster speeds, the separation in limb contact timings becomes more equal, especially between the leading hindlimb and trailing forelimb [32], as does the amount of vertical force and impulse experienced by each limb [31].

These data would suggest that ideal conditions for producing the fastest speeds were evident once cushioning values reached approximately 10 kN, with seemingly little advantage in performance above the knot. Speed may need to be regulated by horses on firmer ground possibly due to changes in limb contact timings to manage limb forces limits [31]. Data from the Japanese Derby between 2016 and 2019, run each year on firm ground in May showed reduction in speed and stride length reflecting a fatigue effect on the second lap of the race [33]. In contrast, analysis of a large dataset of kinematic variables from races in Australia and Tasmania clearly showed an increase in stride length both early and late in races on firm ground compared to synthetic and softer turf [34]. On firmer ground with less cushioning, the limbs are expected to experience higher vertical ground reaction forces because the forces produced due to the up-down motion of the body are not as readily absorbed by the ground. This has been modelled for greyhound gallop

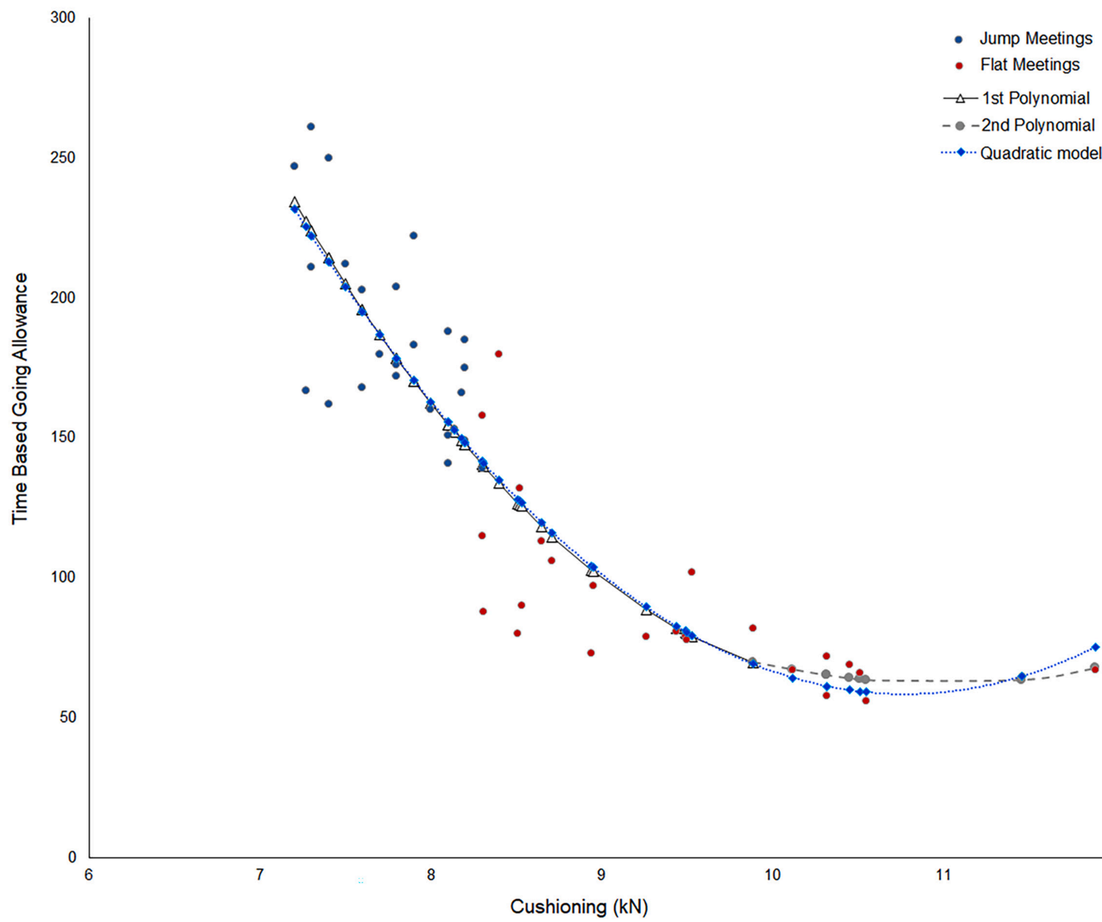

Fig. 4. Data from flat meetings (red) and jump meetings (blue) and the corresponding quadratic (light blue) and two-phase continuous (black-grey) polynomial models of time based going allowance and cushioning (kN) for all 50 meetings.

[35] and vertical force differences have been measured in trotting [36,37] and galloping horses [38] between different surface types. Increased force results in increased strain on the musculoskeletal system which is particularly evident from increased extension of the fetlock joint, the horse's major shock absorber [39,40]. Under these conditions, higher rates of force production and higher amplitudes and frequencies of impact shock are also normally found [38].

The impact of firmer, faster ground conditions has been identified and discussed as a risk factor for injury by many authors previously which was collated recently by [17]. The incidence of catastrophic to minor fractures increased from 1.61% on soft ground to 1.80% on firm ground on ten Japanese flat racecourses between 1997 and 2000 [41]. A study from New Zealand also reported a lower incidence of musculoskeletal injury on soft and dead turf tracks in flat racing compared to good turf [42]. Studies on British turf have indicated an overall decrease in injury rates for flat and jump racing when the ground is softer [43]. The differences in findings between studies might allude to the questions how firm is firm and when is firm too firm? Quantifying acceptable limits of firmness that keep galloping speeds within limb limits must be a key goal for the future of horseracing.

At the opposite end of the range to firm, is heavy where the ground can provide only a limited amount of vertical force to support body weight. At high moisture contents the turf plastically deforms more readily as body weight descends, which absorbs more energy and reduces racing speed. Additional propulsive force from the hindlimbs is envisaged to be necessary when there is reduced vertical support from the ground. This has been demonstrated in trotters on soft sand [36], but to date ground reaction forces at gallop have not been measured in horses on ground with such limited vertical support. The additional muscular effort needed to produce sufficient potential and kinetic energy to maintain speed will likely induce an earlier onset of fatigue as turf going gets softer [44]. Despite this, in a study of flat racing in New Zealand, heavy going did not influence the failure of horses to finish a race [45]. In British National Hunt racing, heavy ground has not been reported as a risk factor for injury, falls or failure to finish [43,46], with the exception of the Grand National [47].

The increase in variability on softer ground, as illustrated in Fig. 4 does indicate a large difference in ground conditions particularly as moisture content increases, as the soil transitions from a friction, through an adhesion to a lubrication phase [48]. The phases are sensitive to soil type and their effect on the shoe-hoof-ground interaction will include the amount of vertical force support, the ability of the hoof to penetrate the surface, the amount of shear resistance to support braking and propulsive forces applied by the horse, the amount of hoof slide and depth of penetration, and the stick-slip relationship between the ground and the hoof [37,49–51]. Further knowledge of the hoof-shoe-ground interaction at moisture contents across these three phases could aid clerks' decision making, particularly in jump racing.

The non-linear relationship between speed and cushioning illustrates the difficulty for clerks of the course in classifying ground. It could be surmised that the difference in going classification between measurement methods used several hours before racing and going classification of performance during the meeting are unlikely to match. This may be due to changes in the ground after measurements have been taken, and/or other factors that may influence performance. These include but are not limited to the physical and mental state of the winning horse [52], the inherent conformation and locomotory action of the winning horse [53,54], the skill of the jockey [55,56] and the way the race was run.

That said, using a tool that provides objective measurements of track material properties that can consistently provide the best estimate of horse performance across racecourses would be a beneficial step forward, as known material properties can also be related to injury [18].

As this study was a proof of concept, the dataset only included a small number of racecourses in South and South-West England. The results may therefore not reflect the speed-going relationship across the extent of racecourses in Britain. A further analysis of a wider dataset is needed to confirm whether the models hold for British racing in general.

The relationships for jump racing were not as strong as for flat racing, as between meetings, the variability was greater. Several key factors are expected to have influenced these results. Firstly, the time-based going allowance for each race meeting was determined from either a chase or a hurdle race, depending on which race resulted in a minimum going value. As such, overall course averages were used in the analysis, although both chase and hurdle courses were measured separately. Future work should aim to separate chase and hurdle going measurements. Softer going at higher moisture contents impacts functional performance in preceding races due to divots, and in this analysis only four of the jump meetings had a minimum going measurement from a race other than the first race. In addition, the functional properties of the ground are particularly sensitive to soil type at higher moisture contents.

For flat racing, an additional limitation was that evapotranspiration was not accounted for specifically, as British racing does not record this information as a matter of course and it is difficult to access it otherwise. Its effect on race times was considered to be small over the approximate three hours during which a race meeting takes place, but its effect on going measurements taken early in the morning compared to going at the time that a race meeting starts are potentially greater.

5. Conclusion

The findings from this study illustrate a range of going that might be found on turf racetracks in South and South-West England and the extent to which this influences racehorse maximal speeds. As important decisions are made on whether horses run based on going knowledge, it is essential that measurements of going must produce data that is relevant to the performance of the horse.

Cushioning was a strong predictor of performance going across all flat and jump race meetings. Not only is the measurement useful as it can be compared with the forces that the horse will experience at gallop, but it also holds promise in predicting performance going across the extent of racecourses in Britain due to the inclusion of race day specific and racecourse specific functional properties within the calculation.

The results indicated that performance was similar across a range of firm ground, which is an important finding, as firm ground is a known injury risk. But, on a wider scale, what is firm turf going? Descriptions and measurements and the resulting influence on performance vary across studies and locations around the world. To assist the horse in producing maximal speeds but at a lower risk of sustaining an injury it would be advantageous to be able to answer the question when is firm too firm? It is recommended that the work is extended across a wider geographic region, which should include aligning cushioning with other performance based measurement methods internationally.

CRediT authorship contribution statement

S.J. Hobbs: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. **A. Tatlisulu:** Data curation, Writing – review & editing. **A. Johnson:** Writing – review & editing. **S.D. Rowlands:** Data curation, Investigation, Methodology, Writing – review & editing. **M. Lucey:** Investigation, Methodology, Writing – review & editing. **J.H. Martin:** Methodology, Writing – review & editing. **R.W. Graydon:** Methodology, Writing – review & editing. **A. J. Northrop:** Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of the paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jevs.2024.105211.

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