Jockey perception of shoe and surface effects on hoof-ground interactions and implications for safety in the galloping thoroughbred racehorse

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Abstract

Riding racehorses is a high-risk profession and optimising safety alongside performance is paramount. Horseshoes play a critical role in providing traction with the ground surface and are therefore a major determinant of safety. However, the subjective perceptions of expert riders influence attitudes towards using different shoes and must be taken into consideration before any changes may be implemented. This study used a questionnaire-based method to evaluate jockey opinion of four shoeing conditions (aluminium, steel, GluShu, barefoot) trialled at gallop over turf and artificial surfaces. Nine Lickert-style questions explored impact, cushioning, responsiveness, grip, uniformity, smoothness of ride, safety, adaptation period and overall rating for each shoe-surface combination. A total of 94 questionnaires, based on 15 horse-rider pairs, were assessed using descriptive statistics and linear mixed models performed in SPSS ($p<0.05$). Data indicate that shoe-type significantly affected all question responses, with the exception of impact. Surface-type significantly affected perception of grip and safety. Overall, jockeys showed a preference for aluminium and steel shoes across both artificial and turf tracks. These rated 'excellent' and were considered to be 'very supportive' in approximately 80% of trials, with a 100% 'active' response, good grip and a quick adaptation period. In contrast, barefoot and GluShus were generally considered 'moderately supportive', with barefoot appearing favourable on the artificial surface. On turf, barefoot was deemed the least smooth, and the only condition that jockeys sometimes marked 'unsafe' (17% of responses). Future work aims to investigate the relationship between jockey opinion and hoof kinematic data.

Key words

Jockey, questionnaire, racehorse, surface, shoeing

1. Introduction

Horseshoes and surface type govern the impact hardness, cushioning, responsiveness, grip and uniformity experienced at the hoof-ground interface during a hoof strike [1]. The selection of horseshoes and surfaces is therefore key to optimising performance and safety in many equestrian disciplines. Nevertheless, in the racing industry, jockeys, horse owners, farriers and veterinarians appear cautious to move away from traditional horseshoe types, namely aluminium and light-steel shoes. This may reflect a lack of study on novel versus existing horseshoe types suited for racehorses. Racing guidelines are currently limited to a small number of epidemiological studies, such as toe clip bans and a general avoidance of unshod hooves on turf in flat races [2]. In the UK, most races are run on turf but training takes place on both turf and artificial surfaces. Proactive shoeing interventions may be one means of improving training and racing conditions, limiting catastrophic injuries and thereby ensuring the sustainability of the sport from ethical and economic perspectives.

The subjective assessment of expert riders regarding racehorse response to shoes and surfaces is an important consideration before any changes may be implemented. Rider perception of horseshoe and surface interaction are likely to influence their opinions on safety and risk-taking behaviour linked to athletic performance and injury. In racing, a jockey positions themselves off the saddle in a two-point seat and their leg joints flex and extend in a rhythmical manner that aligns with the vertical oscillations of their horse's trunk [3]. Consequently, their body moves only a small amplitude with respect to a world inertial frame and is decoupled from the movements of the horse [4]. Haptic communication exchange in racing is therefore limited, relative to other equestrian disciplines [5,6], to points of contact via the reins and jockey lower legs – horse flanks. Jockey sensitivity to horse movements is likely heightened at these positions. Constraints on jockey upper body displacements are expected to be dictated by the horse's hoof, limb and resulting upper body movements. Hence, the latter features may influence the ease with which jockeys feel they can maintain dynamic stability under particular ground surface and shoeing conditions.

The aim of this study was to compare subjective jockey evaluation of fundamental properties of the hoof-surface interaction across different shoe-surface combinations during galloping. We also aimed to evaluate how these assessments translate into jockey opinions on safety and shoe-surface combination preferences.

2. Materials and methods

2.1 Ethics

Ethical approval for this study was received from the RVC Clinical Research Ethical Review Board (URN 2018 1841-2). Informed consent was given by the jockeys, farriers and owners of the horses participating in this study.

2.2 Horse and rider participants

Retired Thoroughbred ex-racehorses in regular work and utilised for jockey education at the British Racing School (BRS) in Newmarket, UK, provided a convenience sample of fourteen horses for this study. All horses were considered sound by the jockey, farriers and BRS management prior to data collection. They ranged in age from 6–20 years old and had masses between 421 and 555 kg. Additional body dimensions and hoof morphometrics are reported in the Supplementary Material (Tables S1–3). Four riders were available for this study: Jockey-1 is currently a racehorse trainer but was previously a jockey, and has over 20 years of experience in the racing industry; Jockey-2 raced for 6 years, 10 years prior to the study, and currently works at the BRS as a riding instructor; Jockey-3 has been working in racing for approximately 3 years, and currently works as a travelling head person, as well as riding 4 horses per day 6 days per week, ranging from yearlings to older horses; Jockey-4 has a category A and point-to-point license, with in excess of 40 rides and 5–6 years of experience.

The same horse and jockey pairings were used throughout so ‘horse-rider combination’ was fixed, while shoe-surface condition varied. This was to ensure any individual horse or rider characteristics would not confound results; such as age [7,8], skill or experience [5,9–13], and underlying movement asymmetries [5,14–16]. All horses were ridden in a race exercise saddle. Saddles and bridles were consistent across trials for each horse-rider dyad, but style and fit differed between horses and it was not possible to evaluate any potential bias arising from tack differences as part of this study. Jockey stirrup lengths varied between 47 and 50% of their leg lengths from the hip down.

2.3 Farriery interventions

Each study horse had its hooves trimmed by a qualified farrier according to a standardised trimming protocol to ensure consistent hoof geometry prior to data collection. This meant hoof geometry was always representative of the beginning of a trimming/shoeing cycle. The duration of the horses’ regular trimming/shoeing cycles are approximately 4 weeks. The horses underwent data trials on artificial (Martin Collins Activ-Track) and turf surfaces in the following four shoeing conditions: 1) barefoot; 2) aluminium raceplates; 3) steel shoes; 4) GluShus (aluminum-rubber composite shoes). The horseshoe selection was based on farriers’ recommendations of existing and novel shoeing conditions to trial and includes relevant and accessible options for racehorses in both training and racing contexts. The four shoe types were applied with five copper-coated mild steel nails. Shoe mass varied between 245–573 g (mean=343±15 g, mean ±2 s.e. unless otherwise stated) for steel, 104–158 g (mean=134±3 g) for aluminium, and 145–249 g (mean=191±7 g) for the GluShus. The different shoe-surface combinations were tested in a randomized order in case of carry-over effects between trials, for example due to tiredness of the horse or rider.

2.4 Racing conditions

Following an initial ridden warm-up, each horse galloped on level (0–2% incline) artificial and turf tracks in each shoeing condition. The tracks curved slightly anti-clockwise. The riders were asked to gallop their horses on both left and right leads for each shoe-surface combination, in case of any laterality bias [17]. Horses were not forced to exercise for a duration beyond what is typical of a short riding session (15–20 minutes), so trials were split across multiple days for each horse-rider dyad. This meant that between 2 and 4 trials would take place per day, with a typical change over period lasting 45 minutes. Data collection took place on the artificial track from summer 2019 through to early spring 2020. Data collection on the turf track was constrained to the 2019 mid-autumn through to early spring 2020 period, due to accessibility restrictions. Surface conditions for the turf track were described by the riders, using terms used within the racing industry to describe "going" [18], and ranged from 'soft' to 'good-firm'. A researcher present across all trials confirmed consistency in descriptions amongst the riders. In the 72 hours preceding and inclusive of data collection, mean temperature was 9.8±2.3ºC, mean rainfall was 0.2±0.1 mm and mean humidity was 81.5±2.5%. Full details on daily weather, 3-day averages, and monthly averages are reported in the supplement.

2.5 Questionnaire

At the end of trials, jockeys were asked to complete a questionnaire. The questionnaire comprised nine Lickert style questions, exploring rider perception of functional shoe-surface properties familiar to them [1,19]. The questions included, where appropriate, brief explanations of the terminology being used and jockeys were openly encouraged to ask for further clarification, if necessary. A copy of the questionnaire is provided in the supplement. In brief:

- Question 1 asked the jockeys about their opinion of hoof impact. Response options available ranged from 'very soft' to 'very hard'. Impact is defined as the shock experienced when the hoof contacts the surface; at this stage the equine limb experiences high deceleration and, due to the low mass of the hoof, low forces [20]. Impact firmness will be related to the hardness of the shoe-surface combination and the initial stiffness during primary impact [1].
- Question 2 explored jockey opinion on the cushioning provided by each shoe-surface combination. Cushioning describes the extent to which the shoe-surface combination feels supportive compared to how much it gives, and reflects the ability of a surface to absorb and reduce peak force [1]. Response options for Question 2 ranged from 'very supportive' to 'no support'.
- Question 3 asked the jockeys about the responsiveness of the shoe-surface combinations. Responsiveness describes how active or springy the hoof-surface interaction is and it is related to deformation and elastic recovery; answer options ranged from 'active' to 'not active'.
- Question 4 investigated jockey opinion on grip. The amount of grip offered by a shoe-surface combination reflects how much the horse's foot slides during landing, turning and push off. Question response options ranged from 'no grip' (very slippery) to 'high grip' (no slip).
- Question 5 asked the jockeys to define the uniformity of the shoe-surface combination. That is, how regular the shoe-surface combination felt when the horse moved across it, ranging from 'variable' to 'uniform'.
- Question 6 asked the jockeys to consider the adaptation period, which is the time taken to adapt to shoe-surface combination. Response options ranged from 'instantaneous' to 'no adaptation'.
- Question 7 asked about the smoothness of ride, ranging from 'very smooth' to 'very disruptive'.
- Question 8 questioned the jockeys on how safe they felt with the shoe type and surface combination, ranging from 'very safe' to 'very unsafe'.

• Finally, in Question 9 we asked the jockeys to provide an overall rating on the shoe-surface combination. Response options for this question ranged from 'very poor' to 'excellent'.

There was also space for the jockeys to provide any further comments on each trial, such as adjustments they had to make when riding in a particular shoe-surface combination. This allowed for the emergence of issues not pre-empted by the researchers.

2.6 Statistical methods

Descriptive statistics were used to investigate jockey responses to the nine questions. Nine linear mixed models were implemented in SPSS to test for significant differences in the responses, under the different shoe and surface conditions. Shoe, surface and 'shoe-surface interaction' were defined as fixed factors and horse-rider pair and day as random factors. Histograms of models' residuals were plotted and inspected for normality. The significance threshold in all statistical tests was set at $p<0.05$. Pearson Product Moment Correlation Coefficients were quantified using estimated marginal mean values from the models for each of the shoe-surface combinations; this allowed us to explore the relationships between question topics.

3. Results

There were 94 questionnaires completed by the jockeys for 94 trials. *Table 1* summarises the trials completed by each horse-rider pair. The answer to question nine was missing in one form, giving a total of 845 responses. The distribution in responses are illustrated in *Figure 1*. There were ten instances where jockeys marked a mid-way point between question answer options: for example, by ticking both 'good' and 'excellent'. These responses were assigned a mid-way score between the selected answers. Five responses to Question 3 had a 'did not notice' response; these were left blank in the linear mixed models. The linear mixed model results for tests of the fixed effects are summarized in *Table 2*. The estimated marginal means from the linear mixed models are provided in *Tables 3–5* for shoe, surface and shoe-surface combinations, respectively. For questions where shoe-types were significantly different, the results of pairwise comparisons of their estimated marginal means, with Bonferroni correction, are given in *Table S5*. For questions where shoe and surface interaction had a significant effect on the responses, pairwise comparisons between estimated marginal means for the different shoe-surface combinations, with Bonferroni correction, are given in *Table S6*.

3.1 Question 1: Impact

Data indicate that barefeet, GluShus and steel shoes felt 'very soft' or 'soft' on impact for both artificial and turf tracks in 55–69% of trials, whereas aluminium shoes on turf were always considered 'very soft'–'soft'. A third of all aluminium trials were considered to be 'very soft' on both surfaces. However, the linear mixed models indicated that shoe-type, surface and shoe-surface interactions did not have a significant effect on jockey perception of impact (all $p>0.05$).

3.2 Question 2: Cushioning

Cushioning was described as ‘very supportive’ for steel and aluminium shoes in approximately 80% of trials on both surfaces, and ‘moderately supportive’ for the majority of barefoot and GluShu trials. The only condition reported to offer limited support was the barefoot on artificial condition, but this was in <7% of responses. No shoe-surface conditions were thought to offer no support. The linear mixed model for this question indicated that shoe-type had a significant effect on jockey perception of cushioning ($p<0.0005$) (*Table 2*). Surface and shoe-type did not have a significant effect on jockey responses ($p>0.05$).

3.3. Question 3: Responsiveness

Steel and aluminium shoes created an active response in 100% of trials across both surfaces, according to the jockeys. In a small number of trials, GluShus (9–10%) and barefoot (13–17%) were considered to be unreactive. However, there were five instances when the jockeys ‘did not notice’ the responsiveness of the barefoot (7% of trials) or GluShu on turf (30% of trials) conditions. The linear mixed model for this question indicated that shoe-type had a significant effect on jockey perception of responsiveness ($p=0.013$) (*Table 2*). Surface and shoe-surface interaction did not have a significant effect on jockey responses ($p>0.05$).

3.4 Question 4: Grip

The highest grip was thought to be conferred by aluminium and steel shoes on the artificial track (92% of responses). These shoeing conditions also offered the most grip on turf: 67 and 75% of responses reported ‘high grip’ for aluminium and steel, respectively. In general, barefoot on turf was considered to provide the least grip, offering ‘moderate grip’ in 92% of trials. The only condition reported to provide no grip and hence feel ‘very slippery’ was the steel on turf condition (8% of trials). Shoe-type and surface both had a significant effect on jockey perception of grip ($p=0.002$, *Table 2*; and $p=0.001$, respectively). Shoe-surface interaction did not have a significant effect on jockey responses to this question ($p>0.05$).

3. 5 Question 5: Uniformity

For steel and GluShu shoes, trials on both turf and artificial surfaces created a uniform response according to the jockeys in 100% of trials. Aluminium shoes created a uniform response in 100% of trials on the artificial surface and 89% of trials on turf. Barefoot on artificial was deemed to feel uniform in 87% of trials, although barefoot on turf was more commonly variable (42% of trials). The linear mixed models reported shoe-type had a significant effect on jockey perception of uniformity ($p<0.0005$). Surface and shoe-surface interaction did not have a significant effect on jockey responses to this question ($p>0.05$).

3.6 Question 6: Adaptation period

The adaptation period for steel and aluminium shoes was nearly always instantaneous. For the GluShus, adaptation occurred either instantaneously or by the end-of the warm up. The horses generally took the longest adapting to the barefoot condition and there were a few occasions on both the turf (8%) and artificial (13%) track when the adaptation was not considered to have taken place until the end of the first run. The linear mixed models confirmed shoe-type had a significant effect on jockey perception of adaptation ($p<0.0005$), but neither surface nor shoe-surface combination had a significant effect on jockey perception of adaptation ($p>0.05$).

3.7 Question 7: Smoothness of the ride

Aluminium and steel shoes created similar jockey responses across surfaces, although with a trend towards increasing smoothness on the artificial track. The barefoot on turf condition was deemed the least smooth, with half of the trials either considered 'neither smooth nor irregular' (42%) or 'irregular' (8%). On the artificial track, barefoot was mostly rated 'smooth' (60%). The linear mixed model for this question indicated that shoe-type had a significant effect on jockey perception of smoothness ($p<0.0005$), but surface and shoe-surface combination did not have a significant effect ($p>0.05$).

3.8 Question 8: Safety

Shoe-type, surface and shoe-surface interaction all had a significant effect on jockey perception of safety ($p<0.0005$, $p=0.004$ and $p=0.027$, respectively). In most cases, all trialled shoe-surface combinations were considered 'safe' or 'very safe'. However, the barefoot on turf condition was felt to be unsafe in 17% of trials. The aluminium and steel shoes were considered 'very safe' in 83–85% of trials on the artificial track and 67–75% of trials on turf. On turf and artificial surfaces, GluShus rated 'safe' in 82% and 90% of trials, respectively.

3.9 Question 9: Overall rating

Shoe-type had a significant effect on jockey perception of impact ($p<0.0005$). Surface and shoe-type did not have a significant effect on jockey responses to this question ($p>0.05$). Steel and aluminium shoes rated 'excellent' in approximately 80% of trials across both surfaces. GluShus rated 'good' in 75 and 85% of trials on the artificial and turf surfaces, respectively. The barefoot condition appeared to be slightly more favoured on the artificial over the turf track.

The three replicate trials (*Table 1*) showed agreement on all questionnaire responses, with the exception of Question 1 in one trial, equating to an individual reproducibility of 96%. In comparison, Jockey-1 and Jockey-3 showed agreement for 58% of responses regarding the performance of Horse-1 in four trials.

4. Discussion

This study sought to evaluate jockey perception of hoof-surface interactions and safety under eight different shoeing and surface conditions. The results emphasise a strong influence of shoeing condition on rider perception of cushioning, responsiveness, grip, uniformity, adaptation, safety and overall rating. The impact experienced on landing, was the only feature explored that showed no difference amongst shoeing conditions. A difference between the artificial and turf tracks was only perceived to be apparent in terms of grip and safety.

Overall preferences suggest jockeys favour the more familiar shoeing conditions, steel and aluminium, and do not consider these to be significantly different from each other based on all nine question topics (*Table S5*). Intriguingly, jockeys' perceptions appear to be in slight conflict with centre of mass displacement patterns for the horses and jockeys under the different shoeing and surface conditions studied here (Horan et al., unpublished data); these data point towards similarities in horse and rider vertical displacements under barefoot and aluminium conditions compared to GluShu and steel. Despite the jockey preferences, there were still occasions when their favoured shoes were associated with undesirable interactions with the surface; for example, the steel was occasionally very slippery on turf.

From the perspective of cushioning (Question 2), barefoot and GluShu shoess provoked a consistent response to each other, which was significantly different from the metal shoes. This may reflect differences in the pressure distribution at the hoof sole in the GluShu and barefoot conditions: the lower rigidity of these materials, relative to metal, may cause the toe to sink less on impact, meaning increased pressure is distributed palmarly. This possible alteration to hoof balance may create the perception of lowered stability and also explain the occasional feelings of unresponsiveness (Question 3). Overall, the steel shoe appeared to offer a mid-way option in terms of grip (Question 4), as it was not significantly different to any of the other shoe-types. However, jockey responses indicate that some caution should be taken when riding with steel shoes on turf, if this is deemed to be occasionally very slippery. Some degree of hoof slip at impact is advantageous for lowering forces during deceleration [21,22] and reducing bending moments on the cannon bone [23]. However, excessive hoof slide can predispose to injury, such as tears to the digital flexor muscles [24]. Nevertheless, the response options for this question did not allow jockeys to distinguish between slip at impact versus slip at foot-off, and this requires further investigation. In the barefoot condition, uniformity (Question 5) was considered to be significantly reduced relative to all other shoeing conditions. Perhaps this is linked to increased hoof deformation on landing in the unshod condition [25] and less restricted hoof rotation.

It was an inevitable limitation of the study that jockeys could not be blinded to the trial conditions. This was because the jockeys had to guide the horses to the appropriate gallop tracks and could identify shoe-types by listening to their sound on the tarmac access routes even without looking directly at the horses' hooves. Consequently, they may have introduced unconscious bias into the results. It is unclear whether the tendency toward a shoeing preference of aluminum and steel over barefoot and GluShus might reflect the jockeys' or horses' prior experience racing and training in these conditions. Indeed, the jockeys perceived an instantaneous adaptation to these conditions (Question 6). Jockey-1 also commented on their horse feeling *"balanced, springy and confident, and in his comfort zone"* and *"comfortable"* to ride when in steel shoes compared to barefoot. However, it is worth noting that the results from this survey are limited to just four jockeys and responses are dominated by the opinions of Jockey-3, simply based on their greater availability to complete ridden trials. Nevertheless, as horse-jockey pairings were fixed, we do not expect differences in jockey experience to have skewed results.

A further limitation of this study was that variability in ground conditions were not well-characterised. The mechanical properties of surfaces, including impact resistance, are highly dependent upon temperature and moisture content [26–31]. Inter and intra-track variability across data collection days may explain the lack of surface effect on most parameters. Although the artificial surface investigated is harrowed regularly as part of regular maintenance, it was noticeably sensitive to changing moisture content, even on hourly timescales. Notably, Jockey-3 commented that *"when the artificial surface is drier it rides slower and the imprint is deep and it feels like there is less grip, whereas if it rains it compacts"*. In contrast, the turf in our study area was always well drained, owing to the underlying chalk lithology, and our access to the track was limited to days when conditions were deemed no harder than 'good-firm' by the jockeys and facilitating staff at the British Racing School. Nevertheless, on the turf surface, Jockey-3 also commented that *"when it is softer it feels safer as the horse's toe sticks in, whereas if it is too firm there is more slip"*. Kinematic studies report that increased loading of the toe at mid-stance on soft surfaces increases forward rotation of the hoof [32]. It is possible that this effect may smooth breakover and facilitate a more stable horse-jockey co-ordination pattern during the propulsive phase, encouraging a safer 'feel'. It is also possible that the agreement between Jockey-1 and Jockey-3 responses, across comparable shoe-surface conditions within Horse-1, was lower than individual jockey response reproducibility because of surface differences. Jockey-1 rode on an unusually cold and frosty day (17/01/2019), when daily humidity was 20% lower than on the day Jockey-3 undertook the same trials (14/03/2020) (Table S4). Although surface variability may also have influenced jockey perception of the shoeing conditions, this is considered unlikely as there was no bias towards testing particular shoeing conditions under certain surface settings.

In terms of impact, it was perhaps surprising that neither shoe nor surface appeared to influence jockey opinion. Previous work has alluded to the importance of both surface-type [33–36] and shoe-type [37–40] on impact vibrations, forces and joint kinematics. However, it is possible that surface effects dominated the degree of shock absorption experienced on impact here relative to the shoeing condition, which is in agreement with previous work [41]. Perhaps more subtle effects of shoeing on impact may be more noticeable on more uniform, hard level surfaces or detectable via hoof mounted sensors, where impact vibrations are amplified relative to the upper body [42]. However, the variable nature of the surfaces across data collection days in this study might explain why the jockeys did not perceive impact to be affected by shoe or surface condition. It is also possible that variations in impact were imperceivable by the rider due to the horse's ability to damp around 70% of impact vibrations at the level of the hoof [43]: the strength of the impact signal transferred to the rider from the horses' upper body is therefore perhaps below detection limits.

To explore the relationship between question topics in more detail, we calculated the Pearson Product Moment Correlation Coefficient between estimated marginal mean values for the shoe-surface combinations (*Table 5*). The direction of the scoring system for each question is provided alongside a correlation matrix of the results (*Fig. 2*). The overall ratings were strongly influenced by cushioning, responsiveness and smoothness (all correlation coefficients >±0.97), and to a lesser extent, but still highly correlated, with safety (-0.89) and grip (0.80). Uniformity was the least associated with the overall rating (0.59), followed by impact (-0.76). Safety showed the strongest correlation with a smooth ride (0.92) and grip (-0.94); this is perhaps unsurprising as a horse-jockey dyad that can move smoothly over stride cycles with secure footing is likely to be stable, and less susceptible to injury. In future, it would be interesting to explore whether hoof kinematic data hold any predictive potential for defining upper body movement responses and associated rider kinematics, as this may help explain why jockeys feel more comfortable and safe in particular conditions. For example, shoe-surface combinations that offer high grip may allow limbs more time to provide weight-bearing and propulsive forces during stance and alter equine pelvic motion [44] and by implication rider motion. Furthermore, moving forward, more specific consideration at the level of the individual horse-rider combination is likely to be advantageous to optimise hoof balance, shock dampening, slip, pressure distribution, breakover and hoof mechanism. For example, in our study, Jockey-3 reported a concern when trialling the GluShus on artificial with Horse-7 of them "*having harder interaction with surface – could have longer lasting leg damage in future from force?*", whereas he commented they were "*very comfortable and supportive*" when riding Horse-1. Exploring new shoeing materials and surface combinations for the racing athlete may offer benefits to the conformationally and orthopaedically compromised horse.

The terms used in Questions 1–5 are possible to quantify objectively [1,19] and our future work will use a custom-built horseshoe testing device to explore the correlation between objective biomechanical measurements, such as hoof accelerations, and jockey opinion. Based on the outputs of this study, which do not indicate significant differences amongst shoes or surfaces based on impact, we intend to place emphasis on exploring the stance and push-off stages of the stride cycle. This will also allow us to build on previous work that has focussed primarily on impact [e.g. 19,44]. This work should form the basis for further studies on factors influencing risk taking behaviour in jockeys and how this can be influenced to decrease jockey injury rate. Globally, the incidence of jockey falls and injuries ranges from 2 to 4 falls and 1 to 2 injuries per 1000 race rides in flat racing and 48 to 91 falls and 5 to 12 injuries per 1000 race rides in jumps racing [46]. Although the risk of racing to horses and their jockeys has been explored based on injury type and prevalence [46–49], attention to the ways in which riders perceive, experience and manage risk has received less attention. Research is pointing towards the importance of feeling a responsibility to care for the horse influencing risk-taking in equestrian sports [50]. Rider perceptions of their own and their horses' abilities are also important [51]. The need to maintain stability over stride cycles, independent of the external environment, appears to be reflected in compensatory cranial-caudal and vertical centre of mass displacement differences between jockeys and their horses (Horan et al., unpublished data). The degree of jockey adaptation required to maintain stability would appear to be related to the shoe-surface combination, and hence the extent of any active involvement deemed necessary is likely to influence jockey opinion. Consequently, investigating how jockeys perceive and accept levels of risk using a multifactorial approach, which also accounts for the role of extrinsic factors such as shoe-type and surfaces, may form a valuable basis of future work.

5. Conclusion

Evaluating jockey opinion of hoof-surface interaction at gallop is helpful for understanding how their safety and stability can be optimized when moving over different surfaces during training and racing. This study used a questionnaire to understand how jockeys perceive the influence of different shoe and surface conditions on hoof kinematics and their feelings of safety. Shoe-type more commonly affected jockey responses than surface-type, but this may reflect variability in ground conditions across data collection days, linked to weather. The safety ratings emphasise smoothness and grip are important associated considerations. Overall ratings suggest jockey shoeing preferences align with the most common current practices of using steel and aluminium shoes, perhaps because these were perceived to offer the most support, and proved to be responsive and uniform across both surfaces, with generally sufficient grip and a smooth feel. However, these conditions are also those most familiar to the riders. This research is expected to form a basis for future work exploring rider behaviour and opinions under different horseshoe-surface combinations at different gaits, on turns and over inclined surfaces.

Author contributions

KH designed the questionnaire with input from TP. KH collected the data with assistance from KK, JC, PD, LB, HC, DH, LH and SM. JC, LB, HC and DH performed all of the hoof trimming and shoeing required. KH processed and analysed the data. KH wrote the manuscript with input from TP. All authors approved the final manuscript before submission.

Competing Interests

We have the following interests: JC and PD are registered farriers; TP is the owner of Equigait, a provider of gait analysis products and services. This does not alter our adherence to all polices on sharing data and materials.

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References

[1] Hobbs SJ, Northropp AJ, Mahaffey C, Martin JH, Murray R, Roepstorff L, et al. Equine Surfaces White Paper 2014.

[2] Authority BH. British Horseracing Authority Rules of Racing. 2020.

[3] Clayton HM, Hobbs SJ. The role of biomechanical analysis of horse and rider in equitation science. Appl Anim Behav Sci 2017;190:123–32. https://doi.org/10.1016/j.applanim.2017.02.011.

[4] Pfau T, Spence A, Starke S, Ferrari M, Wilson A. Modern riding style improves horse racing times. Science (80-) 2009;325:289. https://doi.org/10.1126/science.1174605.

[5] Lagarde J, Peham C, Licka T, Kelso JAS. Coordination dynamics of the horse-rider system. J Mot Behav 2005;37:418–24. https://doi.org/10.3200/JMBR.37.6.418-424.

[6] Blokhuis MZ, Aronsson A, Hartmann E, Van Reenan CG, Keeling L. Assessing the rider's seat and horse's behavior: Difficulties and perspectives. J Appl Anim Welf Sci 2008;11:191–203. https://doi.org/10.1080/10888700802100876.

[7] Butcher MT, Ashley-Ross MA. Fetlock joint kinematics differ with age in thoroughbred racehorses. J Biomech 2002;35:563–71. https://doi.org/10.1016/S0021-9290(01)00223-8.

[8] Addis PR, Lawson SEM. The role of tendon stiffness in development of equine locomotion with age. Equine Vet J 2010;42:556–60. https://doi.org/10.1111/j.2042-3306.2010.00296.x.

[9] Münz A, Eckardt F, Witte K. Horse-rider interaction in dressage riding. Hum Mov Sci 2014;33:227–37. https://doi.org/10.1016/j.humov.2013.09.003.

[10] Peham C, Licka T, Kapaun M, Scheidl M. A new method to quantify harmony of the horse-rider system in dressage. Sport Eng 2001;4:95–101. https://doi.org/10.1046/j.1460-2687.2001.00077.x.

[11] Schöllhorn WI, Peham C, Licka T, Scheidl M. A pattern recognition approach for the quantification of horse and rider interactions. Equine Vet J 2006;38:400–5. https://doi.org/10.1111/j.2042-3306.2006.tb05576.x.

[12] Hitchens PL, Leigh Blizzard C, Jones G, Day LM, Fell J. The association between jockey experience and race-day falls in flat racing in Australia. Inj Prev 2012;18:385–91. https://doi.org/10.1136/injuryprev-2011-040255.

[13] Ferrari M, Pfau T, Wilson AM, Weller R. The effect of training on stride parameters in a cohort of National Hunt racing Thoroughbreds: A preliminary study. Equine Vet J 2009;41:493–7. https://doi.org/10.2746/042516409X374591.

[14] Caviedes MFS, Forbes BS, Pfau T. Repeatability of gait analysis measurements in Thoroughbreds in training n.d.:513–8. https://doi.org/10.1111/evj.12802.

[15] Pfau T, Noordwijk K, Sepulveda Caviedes MF, Persson-Sjodin E, Barstow A, Forbes B, et al. Head, withers and pelvic movement asymmetry and their relative timing in trot in racing Thoroughbreds in training. Equine Vet J 2018;50:117–24. https://doi.org/10.1111/evj.12705.

[16] Symes D, Ellis R. A preliminary study into rider asymmetry within equitation. Vet J 2009;181:34–7. https://doi.org/10.1016/j.tvjl.2009.03.016.

[17] Williams DE, Norris BJ. Laterality in stride pattern preferences in racehorses. Anim Behav 2007. https://doi.org/10.1016/j.anbehav.2007.01.014.

[18] Dufour MJD, Mumford C. GoingStick® technology and electromagnetic induction scanning for naturally- turfed sports surfaces.pdf. Sport Technol 2008;1:125–31. https://doi.org/10.1002/jst.27.

[19] Hernlund E, Egenvall A, Hobbs SJ, Peterson ML, Northrop AJ, Bergh A, et al. Comparing subjective and objective evaluation of show jumping competition and warm-up arena surfaces. Vet J 2017;227:49–57. https://doi.org/10.1016/j.tvjl.2017.09.001.

[20] Thomason JJ, Peterson ML. Biomechanical and Mechanical Investigations of the Hoof-Track Interface in Racing Horses. Vet Clin North Am - Equine Pract 2008;24:57–77. https://doi.org/10.1016/j.cveq.2007.11.007.

[21] Orlande O, Hobbs SJ, Martin JH, Owen AG, Northrop AJ. Measuring hoof slip of the leading limb on jump landing over two different equine arena surfaces. Comp Exerc Physiol 2012;8:33–9. https://doi.org/10.3920/cep11011.

[22] Gustås P, Johnston C, Drevemo S. Ground reaction force and hoof deceleration patterns on two different surfaces at the trot. Equine Comp Exerc Physiol 2006;3:209–16. https://doi.org/10.1017/s147806150667607x.
[23] Pratt GW. Model for injury to the foreleg of the Thoroughbred racehorse. Equine Vet J 1997:30–2. https://doi.org/10.1111/j.2042-3306.1997.tb05048.x.
[24] Peterson, M., Roepstorff, L., Thomason, J.J., Mahaffey, C.A. and McIlwraith CW. Racing surfaces: current progress and future challenges to optimize consistency and performance of track surfaces for fewer horse injuries. Racing Surfaces Test Lab White Pap 2012.
[25] Roepstorff L, Johnston C, Drevemo S. In vivo and in vitro heel expansion in relation to shoeing and frog pressure. Equine Vet J 2001:54–7.
[26] Chateau H, Holden L, Robin D, Falala S, Pourcelot P, Estoup P, et al. Biomechanical analysis of hoof landing and stride parameters in harness trotter horses running on different tracks of a sand beach (from wet to dry) and on an asphalt road. Equine Vet J 2010;42:488–95. https://doi.org/10.1111/j.2042-3306.2010.00277.x.
[27] Mahaffey CA, Peterson ML, Thomason JJ, McIlwraith CW. Dynamic testing of horseshoe designs at impact on synthetic and dirt Thoroughbred racetrack materials. Equine Vet J 2016;48:97–102. https://doi.org/10.1111/evj.12360.
[28] Barrey E, Landjerit B, Wolter R. Shock and vibration during the hoof impact on different track surfaces. Equine Exerc Physiol 1991;1:97–106.
[29] Peterson ML, Reiser RF, Kuo PH, Radford DW, McIlwraith CW. Effect of temperature on race times on a synthetic surface. Equine Vet J 2010;42:351–7. https://doi.org/10.1111/j.2042-3306.2010.00072.x.
[30] Bridge JW, Peterson ML, McIlwraith CW, Beaumont RM. Temperature Effects on Triaxial Shear Strength of Granular Composite Sport Surfaces. J ASTM Int 2010;7:103139. https://doi.org/10.1520/JAI103139.
[31] Ratzlaff MH, Hyde ML, Hutton D V., Rathgeber RA, Balch OK. Interrelationships between moisture content of the track, dynamic properties of the track and the locomotor forces exerted by galloping horses. J Equine Vet Sci 1997;17:35–42. https://doi.org/10.1016/S0737-0806(97)80456-X.
[32] Scheffer CJW, Back W. Effects of 'navicular' shoeing on equine distal forelimb kinematics on different track surface. Vet Q 2001;23:191–5. https://doi.org/10.1080/01652176.2001.9695111.
[33] Barstow A. Does ' hacking ' surface type affect equine forelimb foot placement , movement symmetry or hoof impact deceleration during ridden walk and trot exercise ? 2019;51:108–14. https://doi.org/10.1111/evj.12952.
[34] Setterbo JJ, Garcia TC, Campbell IP, Reese JL, Morgan JM, Kim SY, et al. Hoof accelerations and ground reaction forces of Thoroughbred racehorses measured on dirt, synthetic, and turf track surfaces. Am J Vet Res 2009;70:1220–9. https://doi.org/10.2460/ajvr.70.10.1220.
[35] Symons JE, Garcia TC, Stover SM. Distal hindlimb kinematics of galloping Thoroughbred racehorses on dirt and synthetic racetrack surfaces. Equine Vet J 2014;46:227–32. https://doi.org/10.1111/evj.12113.
[36] Crevier-Denoix N, Pourcelot P, Ravary B, Robin D, Falala S, Uzel S, et al. Influence of track surface on the equine superficial digital flexor tendon loading in two horses at high speed trot. Equine Vet J 2009;41:257–61. https://doi.org/10.2746/042516409X394445.
[37] Back W, van Schie MH, Pol JN. Synthetic shoes attenuate hoof impact in the trotting warmblood horse. Equine Comp Exerc Physiol 2006;3:143–51. https://doi.org/10.1017/ecp200691.
[38] Pardoe CH, Mcguigan MP, Rogerst KM, Rowet LL, Wilson AM, Basic V, et al. The effect of shoe material on the kinetics and kinematics of foot slip at impact on concrete. Equine Vet J 2001:70–3.
[39] Benoit P, Barrey E, Regnault JC, Brochet JL. Comparison of the damping effect of different shoeing by the measurement of hoof acceleration. Acta Anat (Basel) 1993;146:109–13.
[40] Roepstorff L, Johnston C, Drevemo S. The effect of shoeing on kinetics and kinematics during the stance phase. Equine Vet J 1999:279–85. https://doi.org/10.1111/j.2042-3306.1999.tb05235.x.
[41] Hüppler M, Häfner F, Geiger S, Mäder D, Hagen J. Modifying the Surface of Horseshoes: Effects of Eggbar, Heartbar, Open Toe, and Wide Toe Shoes on the Phalangeal Alignment, Pressure Distribution, and the Footing Pattern. J Equine Vet Sci 2016;37:Hüppler, M., Häfner, F., Geiger, S., Mäder, D., . https://doi.org/10.1016/j.jevs.2015.12.009.
[42] Gustas P, Johnston C, Roepstorfft L, Drevemo S. In vivo transmission of impact shock waves in the distal forelimb of the horse. Equine Vet J 2001;33:11–5. https://doi.org/10.1111/j.2042-3306.2001.tb05350.x.
[43] Willemen MA, Jacobs MWH, Schamhardt HC. In vitro transmission and attenuation of impact vibrations in the distal forelimb. Equine Exerc Physiol 1999;5:245–8.
[44] Day P, Collins L, Horan K, Weller R, Pfau T. The Effect of Tungsten Road Nails on Upper Body Movement Asymmetry in Horses Trotting on Tarmac. J Equine Vet Sci 2020;90:1–5. https://doi.org/10.1016/j.jevs.2020.103000.
[45] Roepstorff L. Test of Ollov shoe versus standard iron shoe on different surfaces. Uppsala: 2020.

https://doi.org/10.1017/CBO9781107415324.004.

[46] Hitchens PL, Ryan K, Koch SI, Scollay MC, Peterson ML. A sustainable structure for jockey injury data management for the North American horse racing industry. Injury 2019;50:1418–22. https://doi.org/10.1016/j.injury.2019.06.033.

[47] Hitchens PL, Morrice-West A V., Stevenson MA, Whitton RC. Meta-analysis of risk factors for racehorse catastrophic musculoskeletal injury in flat racing. Vet J 2019;245:29–40. https://doi.org/10.1016/j.tvjl.2018.11.014.

[48] Boden LA, Anderson GA, Charles JA, Morgan KL, Morton JM, Parkin TDH, et al. Risk of fatality and causes of death of Thoroughbred horses associated with racing in Victoria, Australia: 1989-2004. Handb Environ Chem Vol 5 Water Pollut 2006;38:312–8. https://doi.org/10.2746/042516406777749182.

[49] Hitchens PL, Hill AE, Stover SM. Jockey Falls, Injuries, and fatalities associated with thoroughbred and Quarter Horse racing in California, 2007-2011. Orthop J Sport Med 2013;1:1–7. https://doi.org/10.1177/2325967113492625.

[50] Thompson K, Nesci C. Over-riding concerns: Developing safe relations in the high-risk interspecies sport of eventing. Int Rev Sociol Sport 2016;51:97–113. https://doi.org/10.1177/1012690213513266.

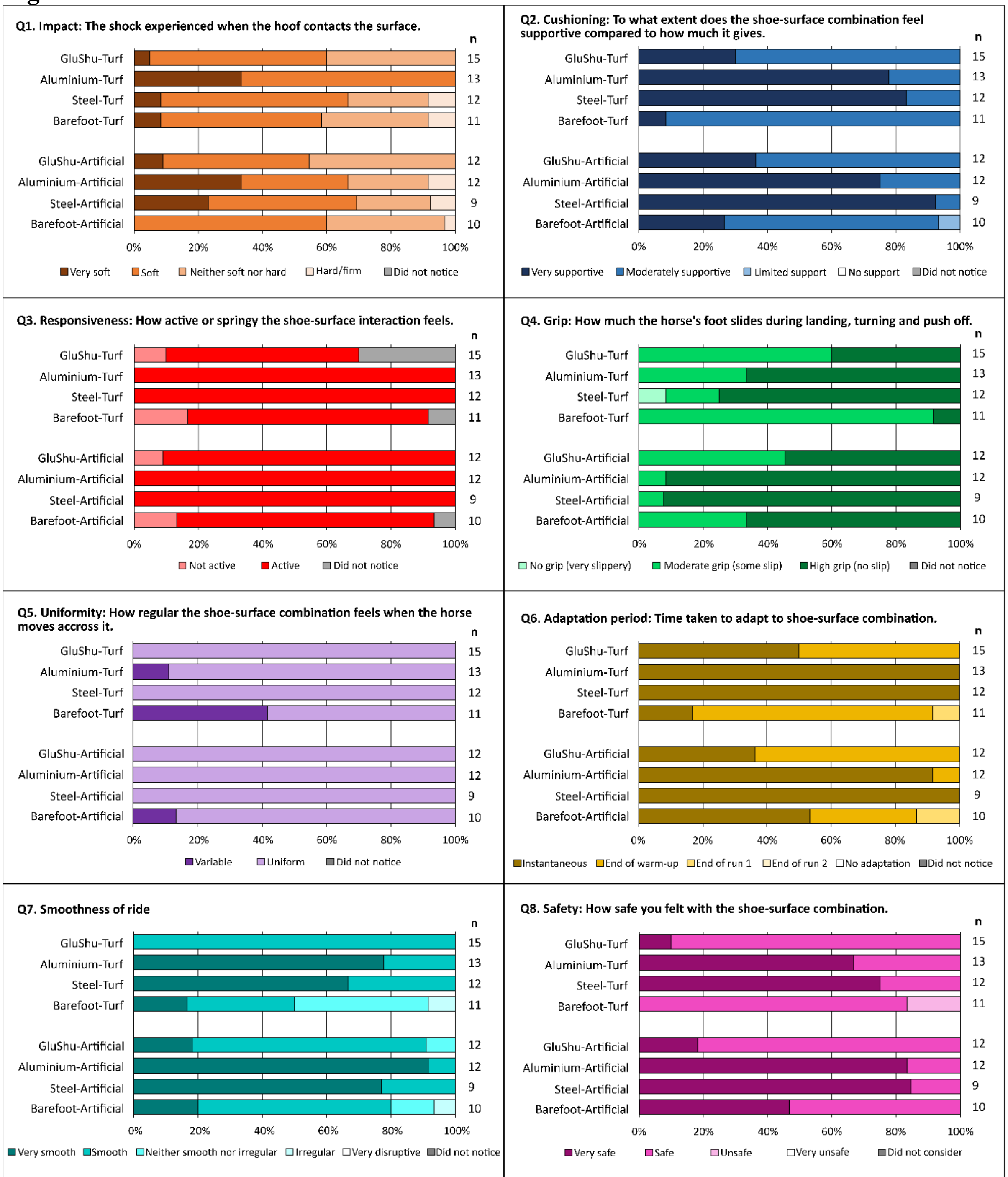
[51] Beauchamp MR, Whinton LC. Self-Efficacy and Other-Efficacy in Dyadic Performance: Riding as One in Equestrian Eventing. J Sport Exerc Psychol 2016;27:245–52. https://doi.org/10.1123/jsep.27.2.245.

[52] Ellis JM, Hollands T. Accuracy of different methods of estimating the weight of horses. Vet Rec 1998;143:335–6. https://doi.org/10.1136/vr.143.12.335.

[53] MetOffice (2020) 'Cambridge NIAB' Available at: https://www.metoffice.gov.uk/pub/data/weather/uk/climate/stationdata/cambridgedata.txt (Accessed: 10/11/2020).

[54] WorldWeatherOnline (2020) 'Newmarket Historical Weather' Available at: https://www.worldweatheronline.com/newmarket-weather-history/suffolk/gb.aspx (Accessed 10/11/2020).

Figures



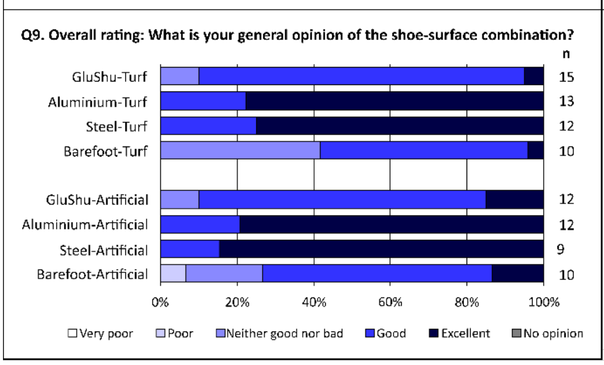
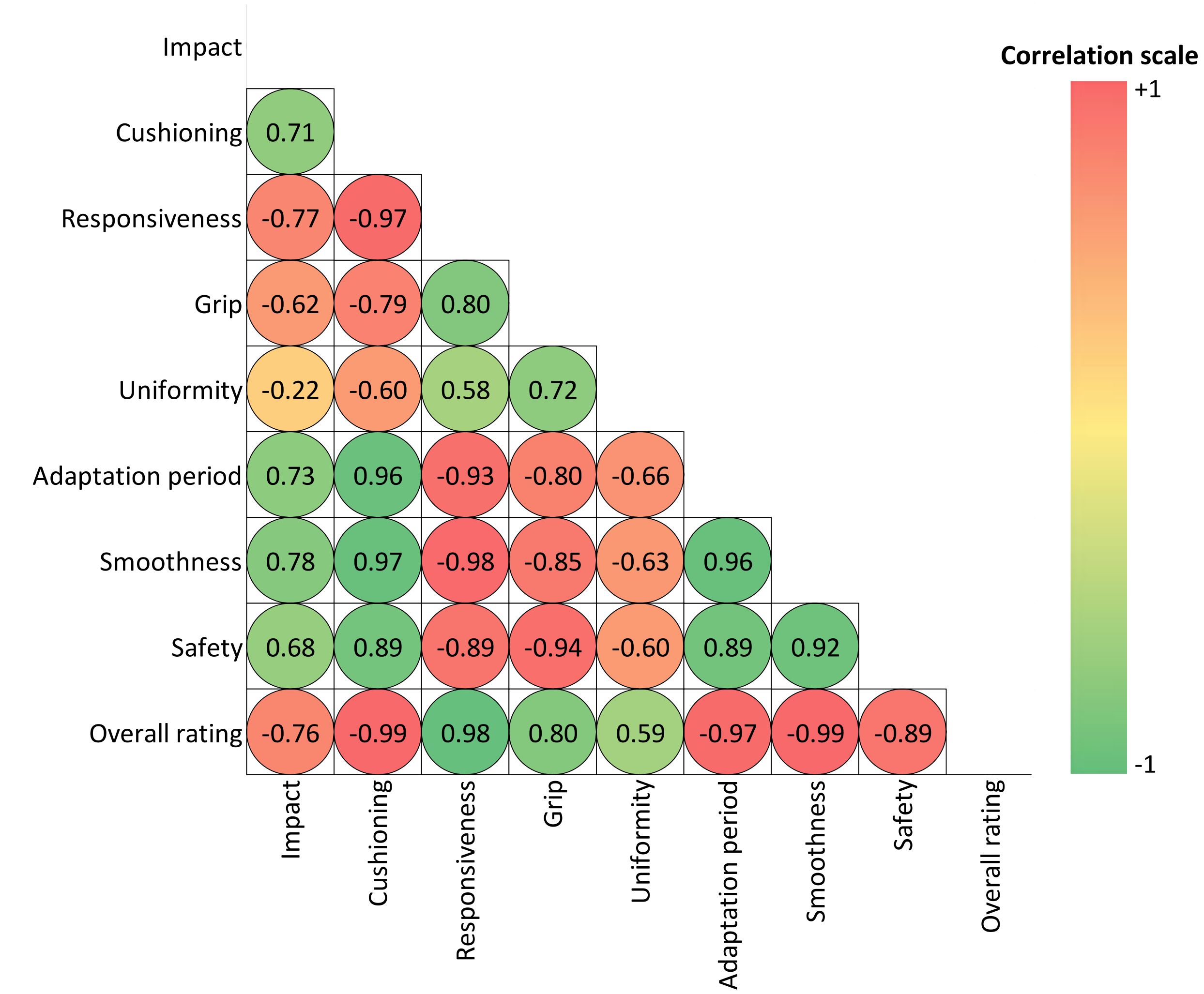


Fig. 1 Bar graphs illustrating jockey responses to nine questions investigating their experience of eight shoe-surface combinations trialled at gallop. (a) Question 1: Impact. (b) Question 2: Cushioning. (c) Question 3: Responsiveness. (d) Question 4: Grip. (e) Question 5: Uniformity. (f) Question 6: Adaptation period. (g) Question 7: Smoothness of ride. (h) Question 8: Safety. (i) Overall rating. The number of surveys completed per shoe-surface condition is indicated by the 'n' values on each chart.



Scoring system from linear mixed models

Q1 Impact	Very soft **(1)**	Soft **(2)**	Neither soft nor hard **(3)**	Hard **(4)**	Very hard **(5)**
Q2 Cushioning	Very supportive **(1)**	Moderately supportive **(2)**	Limited support **(3)**	No support **(4)**	
Q3 Responsiveness	Not active **(1)**	Active **(2)**			
Q4 Grip	No grip (very slippery) **(1)**	Moderate grip (some slip) **(2)**	High grip (no slip) **(3)**		
Q5 Uniformity	Variable **(1)**	Uniform **(2)**			
Q6 Adaptation period	Instantaneous **(1)**	End of warm-up **(2)**	End of first run **(3)**	End of second run **(4)**	No adaptation **(5)**
Q7 Smoothness	Very smooth **(1)**	Smooth **(2)**	Neither smooth nor irregular **(3)**	Irregular **(4)**	Very irregular **(5)**
Q8 Safety	Very safe **(1)**	Safe **(2)**	Unsafe **(3)**	Very unsafe **(4)**	
Q9 Overall rating	Very poor **(1)**	Poor **(2)**	Neither good nor poor **(3)**	Good **(4)**	Excellent **(5)**

Fig. 2 Correlation matrix illustrating the relationship between question responses. Correlation colour scale reflects available range of Pearsson Product Moment Correlation Coefficient values, from +1 (red) to -1 (green). Correlation values were quantified by considering the relationship between estimated marginal means of question scores for the eight possible shoe-surface combinations. The question scoring system is summarized beneath the correlation matrix.

Tables

Table 1. Number of questionnaire responses for each horse-jockey combination under the different shoe-surface combinations.

Horse-ID	Jockey-ID	Barefoot-Artificial	Steel-Artificial	Aluminium-Artificial	GluShu-Artificial	Barefoot-Turf	Steel-Turf	Aluminium-Turf	GluShu-Turf
1	1	1	1	-	-	1	1	-	-
2	2	1	-	1	-	1	-	1	-
3	3	1	2	1	1	1	2	1	1
4	3	1	1	1	1	1	1	1	1
5	3	1	-	1	-	-	-	-	-
6	3	1	1	1	1	-	-	-	1
7	3	1	1	1	1	1	1	-	-
8	4	1	1	1	1	1	1	1	2
9	3	1	-	-	1	-	-	-	-
10	4	1	1	1	1	1	1	1	1
11	4	1	1	1	1	1	1	1	1
12	3	1	1	-	-	1	1	-	-
13	3	1	1	1	1	1	1	1	1
1	3	1	1	1	1	1	1	1	1
14	3	1	1	1	1	1	1	1	1

Table 2. Output of linear mixed models. Shoe, surface and shoe-surface interactions that had a significant effect on jockey responses are highlighted in bold.

Question	Source	F value	p value
1. Impact	Shoe	2.506	0.067
	Surface	0.053	0.819
	Shoe * Surface	0.576	0.633
2. Cushioning	Shoe	16.729	**0.000**
	Surface	0.510	0.478
	Shoe * Surface	0.147	0.932
3. Responsiveness	Shoe	3.890	**0.013**
	Surface	0.257	0.614
	Shoe * Surface	0.146	0.932
4. Grip	Shoe	5.613	**0.002**
	Surface	10.977	**0.001**
	Shoe * Surface	1.221	0.308
5. Uniformity	Shoe	7.763	**0.000**
	Surface	3.138	0.082
	Shoe * Surface	1.977	0.126
6. Adaptation period	Shoe	23.759	**0.000**
	Surface	0.015	0.901
	Shoe * Surface	2.131	0.103
7. Smoothness	Shoe	19.984	**0.000**
	Surface	2.041	0.157
	Shoe * Surface	0.285	0.836
8. Safety	Shoe	19.665	**0.000**
	Surface	9.250	**0.004**
	Shoe * Surface	3.258	**0.027**
9. Overall rating	Shoe	33.275	**0.000**
	Surface	0.806	0.372
	Shoe * Surface	0.154	0.927

Table 3. Estimated marginal means for shoe effects.

Question	Shoe	Mean	Std. Error	df	95% Confidence Interval (lower bound)	95% Confidence Interval (upper bound)
1. Impact	Aluminium	1.971	0.181	39.614	1.604	2.337
	Barefoot	2.452	0.165	30.866	2.114	2.789
	GluShu	2.450	0.183	34.716	2.079	2.822
	Steel	2.279	0.173	32.157	1.927	2.631
2. Cushioning	Aluminium	1.253	0.101	54.650	1.052	1.455
	Barefoot	1.868	0.090	44.588	1.687	2.049
	GluShu	1.686	0.101	43.016	1.481	1.891
	Steel	1.157	0.094	43.139	0.968	1.347
3. Responsiveness	Aluminium	2.011	0.056	49.321	1.899	2.124
	Barefoot	1.829	0.052	41.695	1.724	1.935
	GluShu	1.875	0.061	41.878	1.751	1.998
	Steel	2.000	0.053	39.993	1.894	2.107
4. Grip	Aluminium	2.792	0.103	68.605	2.586	2.997
	Barefoot	2.364	0.091	60.211	2.182	2.546
	GluShu	2.476	0.102	65.477	2.271	2.680
	Steel	2.773	0.095	55.403	2.583	2.964
5. Uniformity	Aluminium	1.947	0.058	61.530	1.832	2.062
	Barefoot	1.723	0.051	52.641	1.621	1.826
	GluShu	2.010	0.058	46.935	1.894	2.127
	Steel	2.010	0.053	49.783	1.903	2.117
6. Adaptation period	Aluminium	1.026	0.102	48.882	0.821	1.232
	Barefoot	1.776	0.093	39.739	1.588	1.964
	GluShu	1.529	0.102	47.963	1.324	1.735
	Steel	1.024	0.097	41.061	0.827	1.220
7. Smoothness	Aluminium	1.153	0.126	86.000	0.902	1.404
	Barefoot	2.242	0.111	86.000	2.021	2.462
	GluShu	1.955	0.125	86.000	1.706	2.203
	Steel	1.282	0.115	86.000	1.054	1.510
8. Safety	Aluminium	1.273	0.100	49.675	1.071	1.474
	Barefoot	1.877	0.090	39.311	1.694	2.059
	GluShu	1.882	0.102	41.951	1.676	2.088
	Steel	1.253	0.094	39.372	1.063	1.444
9. Overall rating	Aluminium	4.781	0.119	50.141	4.542	5.020
	Barefoot	3.689	0.107	40.971	3.473	3.905
	GluShu	3.991	0.122	49.125	3.746	4.236
	Steel	4.761	0.112	40.333	4.534	4.988

Table 4. Estimated marginal means for surface effects.

Question	Surface	Mean	Std. Error	df	95% Confidence Interval (lower bound)	95% Confidence Interval (upper bound)
1. Impact	Artificial	2.271	0.141	16.502	1.974	2.569
	Turf	2.304	0.150	19.253	1.990	2.619
2. Cushioning	Artificial	1.459	0.071	18.721	1.310	1.609
	Turf	1.523	0.078	20.513	1.361	1.685
3. Responsiveness	Artificial	1.941	0.042	18.835	1.854	2.028
	Turf	1.917	0.046	24.328	1.821	2.012
4. Grip	Artificial	2.755	0.070	29.600	2.613	2.897
	Turf	2.447	0.076	31.181	2.293	2.602
5. Uniformity	Artificial	1.969	0.040	21.786	1.886	2.052
	Turf	1.876	0.043	22.898	1.787	1.966
6. Adaptation period	Artificial	1.334	0.078	22.407	1.172	1.495
	Turf	1.344	0.084	25.842	1.172	1.516
7. Smoothness	Artificial	1.572	0.081	86.000	1.412	1.733
	Turf	1.743	0.088	86.000	1.568	1.918
8. Safety	Artificial	1.440	0.075	18.929	1.284	1.597
	Turf	1.702	0.081	21.662	1.534	1.870
9. Overall rating	Artificial	4.350	0.088	20.791	4.166	4.534
	Turf	4.261	0.094	23.169	4.066	4.456

Table 5. Estimated marginal means for shoe-surface combinations.

Question	Shoe	Surface	Mean	Std. Error	df	95% Confidence Interval (lower bound)	95% Confidence Interval (upper bound)
1. Impact	Aluminium	Artificial	2.100	0.219	63.526	1.663	2.536
		Turf	1.841	0.248	73.744	1.348	2.335
	Barefoot	Artificial	2.404	0.199	54.809	2.005	2.803
		Turf	2.500	0.220	62.563	2.060	2.940
	GluShu	Artificial	2.427	0.228	61.676	1.971	2.883
		Turf	2.474	0.239	67.758	1.996	2.951
	Steel	Artificial	2.155	0.214	58.717	1.727	2.584
		Turf	2.403	0.222	62.339	1.960	2.846
2. Cushioning	Aluminium	Artificial	1.268	0.127	77.777	1.016	1.520
		Turf	1.239	0.145	82.521	0.950	1.528
	Barefoot	Artificial	1.806	0.114	73.844	1.579	2.033
		Turf	1.930	0.127	76.312	1.677	2.184
	GluShu	Artificial	1.655	0.133	73.945	1.390	1.919
		Turf	1.717	0.139	77.613	1.440	1.995
	Steel	Artificial	1.109	0.123	74.325	0.864	1.354
		Turf	1.206	0.128	76.043	0.951	1.460
3. Responsiveness	Aluminium	Artificial	2.007	0.069	69.661	1.869	2.145
		Turf	2.015	0.079	75.826	1.858	2.173
	Barefoot	Artificial	1.853	0.065	67.464	1.724	1.981
		Turf	1.806	0.073	70.379	1.662	1.951
	GluShu	Artificial	1.908	0.072	62.898	1.763	2.053
		Turf	1.842	0.089	76.694	1.664	2.019
	Steel	Artificial	1.998	0.067	66.839	1.863	2.132
		Turf	2.003	0.070	69.166	1.863	2.142
4. Grip	Aluminium	Artificial	2.914	0.132	84.514	2.653	3.176
		Turf	2.669	0.152	85.391	2.368	2.971
	Barefoot	Artificial	2.660	0.118	82.656	2.425	2.895
		Turf	2.069	0.132	83.416	1.806	2.331
	GluShu	Artificial	2.544	0.137	84.819	2.271	2.817
		Turf	2.407	0.145	84.021	2.119	2.694
	Steel	Artificial	2.901	0.127	81.637	2.648	3.155
		Turf	2.645	0.132	82.073	2.382	2.909
5. Uniformity	Aluminium	Artificial	2.000	0.074	80.418	1.854	2.147
		Turf	1.894	0.085	83.635	1.725	2.062
	Barefoot	Artificial	1.864	0.066	78.752	1.732	1.995
		Turf	1.583	0.074	79.481	1.436	1.730
	GluShu	Artificial	2.004	0.077	75.663	1.851	2.157
		Turf	2.017	0.081	79.606	1.856	2.178
	Steel	Artificial	2.008	0.071	78.546	1.866	2.149
		Turf	2.012	0.074	79.329	1.865	2.159
6. Adaptation period	Aluminium	Artificial	1.073	0.124	70.842	0.826	1.319
		Turf	0.980	0.141	78.151	0.700	1.260
	Barefoot	Artificial	1.614	0.113	63.636	1.389	1.839

		Turf	1.938	0.125	70.002	1.690	2.187
	GluShu	Artificial	1.627	0.129	73.336	1.371	1.883
		Turf	1.431	0.135	75.107	1.162	1.701
	Steel	Artificial	1.021	0.121	66.909	0.780	1.263
		Turf	1.026	0.125	69.549	0.775	1.276
7. Smoothness	Aluminium	Artificial	1.083	0.165	86.000	0.755	1.412
		Turf	1.222	0.191	86.000	0.843	1.602
	Barefoot	Artificial	2.067	0.148	86.000	1.773	2.361
		Turf	2.417	0.165	86.000	2.088	2.745
	GluShu	Artificial	1.909	0.173	86.000	1.566	2.252
		Turf	2.000	0.181	86.000	1.640	2.360
	Steel	Artificial	1.231	0.159	86.000	0.915	1.547
		Turf	1.333	0.165	86.000	1.005	1.662
8. Safety	Aluminium	Artificial	1.177	0.124	73.778	0.930	1.423
		Turf	1.369	0.141	80.650	1.088	1.650
	Barefoot	Artificial	1.543	0.112	67.232	1.319	1.766
		Turf	2.211	0.124	72.298	1.963	2.459
	GluShu	Artificial	1.845	0.130	71.233	1.586	2.104
		Turf	1.918	0.136	75.236	1.647	2.189
	Steel	Artificial	1.196	0.120	69.123	0.956	1.436
		Turf	1.310	0.125	72.121	1.061	1.559
9. Overall rating	Aluminium	Artificial	4.786	0.147	73.998	4.493	5.079
		Turf	4.776	0.168	79.682	4.441	5.111
	Barefoot	Artificial	3.784	0.133	68.257	3.519	4.049
		Turf	3.594	0.148	72.644	3.300	3.889
	GluShu	Artificial	4.022	0.160	77.456	3.703	4.341
		Turf	3.960	0.161	76.593	3.639	4.281
	Steel	Artificial	4.808	0.143	69.301	4.522	5.094
		Turf	4.714	0.149	71.559	4.417	5.011

Supplementary Information

A copy of the questionnaire used in this study is provided below.

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Shoe Assessment for Equine Racing (S.A.F.E.R)

QUESTIONNAIRE – Jockeys

Date: ______________________

Horse name: __________________________________

Jockey name: __________________________________

Jockey experience: ____

Years of experience: ___________

Please consider the shoe-surface combination you have just ridden with when answering the following questions.

1. Impact: The shock experienced when the hoof contacts the surface.

☐ Very soft ☐ Soft ☐ Neither soft nor hard

☐ Hard ☐ Very hard ☐ Did not notice

2. Cushioning: To what extent does the shoe-surface combination feel supportive compared to how much it gives.

☐ Very supportive ☐ Moderately supportive

☐ Limited support ☐ No support ☐ Did not notice

3. Responsiveness: How active or springy the hoof-surface interaction feels when the horse is ridden in this shoe type.

☐ Not active ☐ Active ☐ Did not notice

4. Grip: How much the horse's foot slides during landing, turning and push off.

☐ No grip (very slippery) ☐ Moderate grip (some slip)

☐ High grip (no slip) ☐ Did not notice

5. Uniformity: How regular the shoe-surface combination feels when the horse moves across it.

☐ Variable ☐ Uniform ☐ Did not notice

6. Adaptation period. Time taken to adapt to shoe-surface combination.

☐ Instantaneous ☐ End of warm-up ☐ End of first run

☐ End of second run ☐ No adaptation ☐ Did not notice

7. Smoothness of ride.

☐ Very smooth ☐ Smooth ☐ Neither smooth nor irregular

☐ Irregular ☐ Very irregular ☐ Did not notice

8. Safety: How safe you felt with the shoe type and surface combination.

☐ Very safe ☐ Safe ☐ Unsafe

☐ Very unsafe ☐ Did not consider

9. Overall rating: What is your general opinion of the shoe-surface combination?

☐ Very poor ☐ Poor ☐ Neither good nor poor

☐ Good ☐ Excellent

10. Any further comments. Please provide any additional comments on your perception of the ride, ride safety or any adjustments you had to make when riding with this shoe-surface combination.

Table S1. Horse heights and masses.

Horse ID	Horse age (year born)	Height (hh)	Trunk circumference (cm)	Body length (cm)	Estimated weight (formula) (kg)†	Estimated weight (weigh tape) (kg)
1	2007	16.1	192.0			511.0
2	2004	16.2	192.0	160	497	511.0
3	2006	16.3	190.0	156	474	490.0
4	2000	16.1	186.0	170	495	464.0
5	2006	15.3	185.5	155	451	461.0
6	2011	16.1	191.0	164	504	498.0
7	2010	16.2	185.0	166	478	458.0
8	2011	16.1	189.0	157	472	484.0
9	2008	16.0	186.5			467.0
10	2007	16.1	188.5	164	493	480.0
11	2009	15.3	184.5	159	458	454.5
12	2012	17.0	197.5	168	555	542.0
13	2014	16.3	187.0	160	471	470.0
14	2010	16.1	182.0	151	421	438.0

†formula uses trunk circumference and body length dimensions: weight (kg) = girth^2 × length (cm) /11,877 [52]

Table S2. Additional horse body morphometric data

Horse ID	Neck length (cm) (poll - end of cervical	Neck circumference (cm)	Head length (cm)	Forelimb length: scapula-ground (cm)		Forelimb length: carpus-ground (cm)		Metacarpus circumference (cm)		Hindlimb length: hip down (cm)		Hindlimb length: tarsus down (cm)		Metatarsus circumference (cm)	
				Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
1	116		54	158.0	159.0	49.0	49.0			136.0	136.0	52.0	52.0		
2	74	114.0	61	161.0	164.0	50.0	52.0			142.0	141.0	55.0	53.0		
3	72	109.0	61	162.0	163.0	51.0	51.0	22.0	21.5	150.0	155.0	56.5	56.5	25.0	25.0
4	75	125.5	55	161.0	161.0	41.0	40.0	20.1	20.0	145.0	144.0	45.0	44.0	22.0	22.0
5	65	108.5	56			39.0	40.0	19.5	19.0	143.0	143.0	45.0	44.5	22.5	22.5
6	72	107.0	54	163.0	162.0	45.5	45.0	21.0	21.1	150.5	147.5	54.0	52.5	25.0	23.5
7	71	111.5	53	160.0	160.0	47.0	42.5	21.0	21.0	147.0	148.0	50.0	48.5	25.0	24.0
8	64	106.0	62	161.0	161.0	44.5	44.0	22.5	21.5	143.5	144.5	51.0	49.0	26.0	26.0
9	75	112.0	54			46.0	47.5	21.0	20.5	145.0	145.5	55.0	54.0	22.0	22.5
10	71	117.0	52	160.0	160.0	45.5	46.5	21.5	21.5	146.5	147.5	52.5	52.0	24.0	24.0
11	67	119.0	63	159.5	158.0	44.5	45.0	26.0	27.5	144.5	144.0	52.0	50.5	28.0	25.5
12	76	121.0	61	166.0	166.5	49.0	49.0	29.5	30.5	152.0	150.0	53.0	54.0	32.5	31.5
13	65	118.0	60	159.0	159.0	48.0	48.0	20.0	20.0	145.0	142.0	54.0	56.0	22.5	22.0
14	60	113.0	57	159.0	160.0	48.0	48.0	21.0	21.0	145.0	145.0	57.5	57.0	22.5	23.0

Table S3. Horse hoof morphometrics and shoe masses.

Horse ID	Circumference at the coronet (cm)				Dorsal hoof wall angle (degrees)*				Shoe mass (g)								
	Right fore	Left fore	Right hind	Left hind	Right fore	Left fore	Right hind	Left hind	Steel	2 s.e.	n	Aluminium	2 s.e.	n	GluShu	2 s.e.	n
1	32.5	32.0	31.0	31.0	51.3	46.2*(2)	47.2*(2)	48.5* (2)	337	21	7	141	15	4	203	2	4
2	32.0	32.0	32.0	31.5								139	4	4			
3	37.5	37.6	38.0	37.5					388	17	7	145	9	8	214	27	4
4	35.0	36.0	35.5	35.0	43.9	44.8	53.8	55.8	352	24	8	143	8	8	222	29	4
5	33.0	34.0	33.5	31.0	51.2	53.4	51.0	54.9				124		1			
6	31.0	31.0	31.5	30.0	55.5* (2)	54.8* (2)	53.9* (2)	53.4	273	12	4	119		4	169	15	4
7	35.0	36.0	35.6	35.5	51.3* (3)	49.4* (3)	50.5* (3)	48.4	347	24	7	140	4	4	197	27	4
8	34.0	35.0	35.0	35.0	52.2* (3)	53.2* (3)	46.2* (3)	44.0* (3)	297	27	8	130	3	8	182	9	8
9	33.0	33.0	34.0	34.5	49.0	50.4	51.4	48.5							172	2	4
10	36.5	36.0	36.5	37.1	49.3* (2)	50.8* (2)	50.1*(2)	48.2* (2)	352	24	8	143	8	8	203	20	8
11	34.0	36.0	35.0	36.0	45.4* (3)	52* (3)	49.6* (3)	45.4* (3)	330	21	8	132	4	8	192	14	8
12	40.0	40.0	40.0	39.6	52.7	51.3	44.2	47.3	511	68	4						
13	33.0	33.5	34.5	34.5	52.1* (2)	50.0* (2)	52.3 *(2)	51.0* (2)	339	25	3	130	4	3	189	13	4
14	32.0	31.5	32.0	32.5	44.1* (2)	49.2* (2)	49.6*(2)	48.3* (2)	271	38	4	108	3	4	160	17	4

*Average dorsal hoof wall angle when measurements were repeated on different data collection days. Numbers in brackets refer to the number of measurements available.

Table S4. Weather data for data collection days.

Data collection date	Monthly Tmax (° C)*	Monthly Tmin (° C)*	Monthly days of air frost*	3 day average T (° C)†	3 day Tmin (° C)†	3 day Tmax (° C)†	3 day average rain (mm)†	3 day min rain (mm)†	3 day max rain (mm)†	3 day average humidity (%)†	3 day min humidity (%)†	3 day max humidity (%)†	Average daily T (° C)□	Average daily rain (mm)□	Average daily humidity (%)□	Total trials
17/01/2019	6.7	1	13	5.5	2	10	0.4	0	3.7	84.6	59	94	3.5	0.0	60.5	4
15/02/2019	11.6	1.7	11	6.5	3	11	0.0	0	0	84.7	63	96	11.0	0.0	65.0	4
08/06/2019	20.1	10.8	0	12.9	9	18	0.4	0	3.2	79.8	48	97	13.0	0.1	76.5	3
06/07/2019	24.1	13.4	0	16.6	10	23	0.0	0	0.2	78.8	58	95	16.7	0.0	83.3	5
03/08/2019	24.2	12.7	0	17.5	13	22	0.4	0	3.7	81.7	59	98	20.5	0.0	66.0	3
10/08/2019	24.2	12.7	0	18.9	13	24	0.4	0	3	72.1	47	94	18.5	0.0	65.5	3
24/08/2019	24.2	12.7	0	18.3	12	25	0.0	0	0.5	71.6	49	93	23.0	0.0	54.0	4
07/09/2019	20.2	10.2	0	13.0	9	17	0.1	0	0.7	71.0	44	94	15.7	0.1	63.0	6
28/09/2019	20.2	10.2	0	14.3	11	18	0.4	0	3	81.0	59	93	15.5	0.0	73.0	4
05/10/2019	14.3	6.9	1	10.7	6	15	0.2	0	2.5	77.1	56	96	14.0	0.0	66.0	4
25/10/2019	14.3	6.9	1	10.4	6	14	0.1	0	0.9	89.0	74	96	12.5	0.5	81.0	4
16/11/2019	9.3	3.6	5	5.3	-1	9	0.5	0	3.5	86.3	70	94	7.0	0.0	76.7	5
23/11/2019	9.3	3.6	5	6.4	2	10	0.1	0	1.2	87.3	77	93	9.5	0.1	88.5	6
11/01/2020	9.1	3.9	4	7.4	3	13	0.6	0	8.7	87.7	78	96	9.0	0.0	82.0	3
18/01/2020	9.1	3.9	4	6.2	2	10	0.2	0	1.7	84.5	76	94	3.5	0.0	82.5	6
31/01/2020	9.1	3.9	4	5.9	1	12	0.0	0	0	86.3	71	95	11.0	0.0	87.0	6
07/02/2020	10.2	3.2	4	4.5	2	9	0.0	0	0.1	85.2	63	95	5.5	0.0	74.0	6
08/02/2020	10.2	3.2	4	5.2	1	9	0.0	0	0.2	85.9	63	95	7.5	0.0	78.0	8
14/02/2020	10.2	3.2	4	4.4	2	8	0.3	0	2.9	79.5	56	94	6.0	0.0	84.0	4
14/03/2020	11.1	2.5	4	6.6	3	13	0.2	0	1.1	76.3	58	91	9.7	0.8	80.3	6

*data published by the MetOffice for the nearest weather station (Cambridge: 543500E 260600N, Latitude = 52.245 Longitude = 0.102, 26 m amsl). T=temperature.

†data published by 'WorldWeatherOnline' (2020). Data are provided in 3 hourly intervals. The 3 day average starts 72 hours preceding (and is inclusive of) the 3 hour slot in which the last daily data trial takes place.

□data published by 'WorldWeatherOnline' (2020). Data are provided in 3 hourly intervals. Hours included in average span data collection duration (averaged intervals vary between 3 and 9 hours).

Table S5. Pairwise comparisons between shoe-types for questions in which shoe had a significant effect on jockey responses. A bonferroni correction was applied. Significant differences are highlighted in bold.

Question	Shoe	Comparison shoe	Mean Difference between shoe and comparison shoe	Std. Error	df	Significance	95% Confidence Interval for Difference Lower bound	95% Confidence Interval for Difference Upper bound
1. Impact	NA	NA	NA	NA	NA	NA	NA	NA
2. Cushioning	Aluminium	Barefoot	-0.615	0.121	69.238	**0.000**	-0.945	-0.285
		GluShu	-0.433	0.131	73.346	**0.009**	-0.789	-0.077
		Steel	0.096	0.125	78.099	1.000	-0.243	0.435
	Barefoot	Aluminium	0.615	0.121	69.238	**0.000**	0.285	0.945
		GluShu	0.182	0.124	75.102	0.873	-0.153	0.518
		Steel	0.711	0.116	72.008	**0.000**	0.397	1.024
	GluShu	Aluminium	0.433	0.131	73.346	**0.009**	0.077	0.789
		Barefoot	-0.182	0.124	75.102	0.873	-0.518	0.153
		Steel	0.529	0.124	77.923	**0.000**	0.192	0.865
	Steel	Aluminium	-0.096	0.125	78.099	1.000	-0.435	0.243
		Barefoot	-0.711	0.116	72.008	**0.000**	-1.024	-0.397
		GluShu	-0.529	0.124	77.923	**0.000**	-0.865	-0.192
3. Responsiveness	Aluminium	Barefoot	0.182	0.066	65.595	**0.045**	0.003	0.361
		GluShu	0.137	0.074	55.063	0.422	-0.066	0.339
		Steel	0.011	0.067	72.756	1.000	-0.170	0.192
	Barefoot	Aluminium	-0.182	0.066	65.595	**0.045**	-0.361	-0.003
		GluShu	-0.045	0.071	55.220	1.000	-0.240	0.150
		Steel	-0.171	0.063	68.259	**0.049**	-0.341	-0.001
	GluShu	Aluminium	-0.137	0.074	55.063	0.422	-0.339	0.066
		Barefoot	0.045	0.071	55.220	1.000	-0.150	0.240
		Steel	-0.125	0.070	71.859	0.468	-0.316	0.065
	Steel	Aluminium	-0.011	0.067	72.756	1.000	-0.192	0.170
		Barefoot	0.171	0.063	68.259	**0.049**	0.001	0.341
		GluShu	0.125	0.070	71.859	0.468	-0.065	0.316

Question	Shoe	Comparison shoe	Mean Difference between shoe and comparison shoe	Std. Error	df	Significance	95% Confidence Interval for Difference Lower bound	95% Confidence Interval for Difference Upper bound
4. Grip	Aluminium	Barefoot	0.427	0.130	77.508	**0.009**	0.075	0.780
		GluShu	0.316	0.138	78.287	0.148	-0.057	0.689
		Steel	0.018	0.133	79.757	1.000	-0.341	0.377
	Barefoot	Aluminium	-0.427	0.130	77.508	**0.009**	-0.780	-0.075
		GluShu	-0.111	0.130	79.685	1.000	-0.463	0.241
		Steel	-0.409	0.124	77.988	**0.009**	-0.744	-0.074
	GluShu	Aluminium	-0.316	0.138	78.287	0.148	-0.689	0.057
		Barefoot	0.111	0.130	79.685	1.000	-0.241	0.463
		Steel	-0.298	0.132	79.130	0.161	-0.655	0.059
	Steel	Aluminium	-0.018	0.133	79.757	1.000	-0.377	0.341
		Barefoot	0.409	0.124	77.988	0.009	0.074	0.744
		GluShu	0.298	0.132	79.130	0.161	-0.059	0.655
5. Uniformity	Aluminium	Barefoot	0.224	0.072	71.741	0.016	0.028	0.419
		GluShu	-0.063	0.077	71.083	1.000	-0.273	0.146
		Steel	-0.063	0.074	79.397	1.000	-0.263	0.137
	Barefoot	Aluminium	-0.224	0.072	71.741	**0.016**	-0.419	-0.028
		GluShu	-0.287	0.073	73.478	**0.001**	-0.484	-0.090
		Steel	-0.286	0.068	74.329	**0.000**	-0.472	-0.101
	GluShu	Aluminium	0.063	0.077	71.083	1.000	-0.146	0.273
		Barefoot	0.287	0.073	73.478	**0.001**	0.090	0.484
		Steel	0.001	0.073	79.217	1.000	-0.198	0.199
	Steel	Aluminium	0.063	0.074	79.397	1.000	-0.137	0.263
		Barefoot	0.286	0.068	74.329	**0.000**	0.101	0.472
		GluShu	-0.001	0.073	79.217	1.000	-0.199	0.198
6. Adaption period	Aluminium	Barefoot	-0.75	0.112	76.926	**0.000**	-1.054	-0.446
		GluShu	-0.503	0.119	77.820	**0.000**	-0.825	-0.180
		Steel	0.003	0.115	78.450	1.000	-0.308	0.314

Question	Shoe	Comparison shoe	Mean Difference between shoe and comparison shoe	Std. Error	df	Significance	95% Confidence Interval for Difference Lower bound	95% Confidence Interval for Difference Upper bound
	Barefoot	Aluminium	0.75	0.112	76.926	**0.000**	0.446	1.054
		GluShu	0.247	0.113	78.259	0.187	-0.058	0.552
		Steel	0.753	0.107	77.317	**0.000**	0.464	1.042
	GluShu	Aluminium	0.503	0.119	77.820	**0.000**	0.180	0.825
		Barefoot	-0.247	0.113	78.259	0.187	-0.552	0.058
		Steel	0.506	0.114	77.825	**0.000**	0.197	0.814
	Steel	Aluminium	-0.003	0.115	78.450	1.000	-0.314	0.308
		Barefoot	-0.753	0.107	77.317	**0.000**	-1.042	-0.464
		GluShu	-0.506	0.114	77.825	**0.000**	-0.814	-0.197
7. Smoothness	Aluminium	Barefoot	-1.089	0.168	86	**0.000**	-1.543	-0.635
		GluShu	-0.802	0.178	86	**0.000**	-1.282	-0.322
		Steel	-0.129	0.171	86	1.000	-0.590	0.331
	Barefoot	Aluminium	1.089	0.168	86	**0.000**	0.635	1.543
		GluShu	0.287	0.167	86	0.537	-0.164	0.739
		Steel	0.96	0.159	86	**0.000**	0.529	1.390
	GluShu	Aluminium	0.802	0.178	86	**0.000**	0.322	1.282
		Barefoot	-0.287	0.167	86	0.537	-0.739	0.164
		Steel	0.672	0.170	86	0.001	0.214	1.131
	Steel	Aluminium	0.129	0.171	86	1.000	-0.331	0.590
		Barefoot	-0.96	0.159	86	**0.000**	-1.390	-0.529
		GluShu	-0.672	0.170	86	**0.001**	-1.131	-0.214
8. Safety	Aluminium	Barefoot	-0.604	0.114	68.371	**0.000**	-0.914	-0.294
		GluShu	-0.609	0.126	71.226	**0.000**	-0.950	-0.268
		Steel	0.020	0.119	76.187	1.000	-0.302	0.342
	Barefoot	Aluminium	0.604	0.114	68.371	**0.000**	0.294	0.914
		GluShu	-0.005	0.119	72.859	1.000	-0.327	0.317
		Steel	0.624	0.109	71.328	**0.000**	0.328	0.919
	GluShu	Aluminium	0.609	0.126	71.226	**0.000**	0.268	0.950

Question	Shoe	Comparison shoe	Mean Difference between shoe and comparison shoe	Std. Error	df	Significance	95% Confidence Interval for Difference Lower bound	95% Confidence Interval for Difference Upper bound
		Barefoot	0.005	0.119	72.859	1.000	-0.317	0.327
		Steel	0.629	0.118	76.811	**0.000**	0.309	0.949
	Steel	Aluminium	-0.020	0.119	76.187	1.000	-0.342	0.302
		Barefoot	-0.624	0.109	71.328	**0.000**	-0.919	-0.328
		GluShu	-0.629	0.118	76.811	**0.000**	-0.949	-0.309
9. Overall rating	Aluminium	Barefoot	1.092	0.138	74.781	**0.000**	0.718	1.467
		GluShu	0.79	0.148	75.221	**0.000**	0.389	1.191
		Steel	0.020	0.141	76.684	1.000	-0.363	0.403
	Barefoot	Aluminium	-1.092	0.138	74.781	**0.000**	-1.467	-0.718
		GluShu	-0.302	0.141	77.056	0.209	-0.682	0.079
		Steel	-1.072	0.131	75.312	**0.000**	-1.428	-0.716
	GluShu	Aluminium	-0.79	0.148	75.221	**0.000**	-1.191	-0.389
		Barefoot	0.302	0.141	77.056	0.209	-0.079	0.682
		Steel	-0.77	0.142	75.307	**0.000**	-1.155	-0.386
	Steel	Aluminium	-0.020	0.141	76.684	1.000	-0.403	0.363
		Barefoot	1.072	0.131	75.312	**0.000**	0.716	1.428
		GluShu	0.77	0.142	75.307	**0.000**	0.386	1.155

Table S6. Pairwise comparisons between shoe-surface combinations types for question 8 (safety). This question showed jockey responses to be significantly affected by shoe-surface interaction. A bonferroni correction was applied. Significant differences are highlighted in bold.

Shoe-surface combination	Comparison shoe-surface combination	Mean Difference between shoe-surface combinations	Std. Error	df	Significance	95% Confidence Interval for Difference (lower bound)	95% Confidence Interval for Difference (upper bound)
Aluminium-Artificial	Aluminium-Turf	-0.192	0.174	73.897	1.000	-0.756	0.372
	Barefoot-Artificial	-0.366	0.149	65.295	0.476	-0.852	0.121
	Barefoot-Turf	-1.034	0.162	74.347	**0.000**	-1.560	-0.508
	GluShu-Artificial	-0.668	0.167	73.690	**0.004**	-1.209	-0.128
	GluShu-Turf	-0.742	0.172	72.725	**0.001**	-1.299	-0.184
	Steel-Artificial	-0.020	0.157	71.198	1.000	-0.528	0.488
	Steel-Turf	-0.133	0.164	74.297	1.000	-0.664	0.398
Aluminium-Turf	Aluminium-Artificial	0.192	0.174	73.897	1.000	-0.372	0.756
	Barefoot-Artificial	-0.174	0.167	75.128	1.000	-0.716	0.368
	Barefoot-Turf	-0.842	0.170	65.729	**0.000**	-1.397	-0.288
	GluShu-Artificial	-0.476	0.180	74.606	0.276	-1.059	0.106
	GluShu-Turf	-0.549	0.181	73.618	0.093	-1.136	0.037
	Steel-Artificial	0.173	0.173	74.487	1.000	-0.389	0.734
	Steel-Turf	0.059	0.173	72.251	1.000	-0.503	0.621
Barefoot-Artificial	Aluminium-Artificial	0.366	0.149	65.295	0.476	-0.121	0.852
	Aluminium-Turf	0.174	0.167	75.128	1.000	-0.368	0.716
	Barefoot-Turf	-0.668	0.153	74.209	**0.001**	-1.164	-0.173
	GluShu-Artificial	-0.303	0.158	74.590	1.000	-0.814	0.209
	GluShu-Turf	-0.376	0.164	75.137	0.696	-0.907	0.156
	Steel-Artificial	0.346	0.147	67.356	0.595	-0.131	0.824
	Steel-Turf	0.233	0.154	75.355	1.000	-0.266	0.732
Barefoot-Turf	Aluminium-Artificial	1.034	0.162	74.347	**0.000**	0.508	1.560
	Aluminium-Turf	0.842	0.170	65.729	**0.000**	0.288	1.397
	Barefoot-Artificial	0.668	0.153	74.209	**0.001**	0.173	1.164
	GluShu-Artificial	0.366	0.168	74.571	0.900	-0.177	0.909
	GluShu-Turf	0.293	0.170	75.827	1.000	-0.257	0.843

	Steel-Artificial	1.015	0.158	73.623	**0.000**	0.501	1.528
	Steel-Turf	0.901	0.158	67.945	**0.000**	0.387	1.415
GluShu-Artificial	Aluminium-Artificial	0.668	0.167	73.690	**0.004**	0.128	1.209
	Aluminium-Turf	0.476	0.180	74.606	0.276	-0.106	1.059
	Barefoot-Artificial	0.303	0.158	74.590	1.000	-0.209	0.814
	Barefoot-Turf	-0.366	0.168	74.571	0.900	-0.909	0.177
	GluShu-Turf	-0.073	0.170	70.422	1.000	-0.627	0.480
	Steel-Artificial	0.649	0.162	74.812	**0.004**	0.124	1.174
	Steel-Turf	0.535	0.165	75.250	0.050	2.392E-05	1.071
GluShu-Turf	Aluminium-Artificial	0.742	0.172	72.725	**0.001**	0.184	1.299
	Aluminium-Turf	0.549	0.181	73.618	0.093	-0.037	1.136
	Barefoot-Artificial	0.376	0.164	75.137	0.696	-0.156	0.907
	Barefoot-Turf	-0.293	0.170	75.827	1.000	-0.843	0.257
	GluShu-Artificial	0.073	0.170	70.422	1.000	-0.480	0.627
	Steel-Artificial	0.722	0.167	74.469	**0.001**	0.181	1.263
	Steel-Turf	0.609	0.167	71.020	**0.015**	0.065	1.152
Steel-Artificial	Aluminium-Artificial	0.020	0.157	71.198	1.000	-0.488	0.528
	Aluminium-Turf	-0.173	0.173	74.487	1.000	-0.734	0.389
	Barefoot-Artificial	-0.346	0.147	67.356	0.595	-0.824	0.131
	Barefoot-Turf	-1.015	0.158	73.623	**0.000**	-1.528	-0.501
	GluShu-Artificial	-0.649	0.162	74.812	**0.004**	-1.174	-0.124
	GluShu-Turf	-0.722	0.167	74.469	**0.001**	-1.263	-0.181
	Steel-Turf	-0.113	0.157	72.173	1.000	-0.622	0.396
Steel-Turf	Aluminium-Artificial	0.133	0.164	74.297	1.000	-0.398	0.664
	Aluminium-Turf	-0.059	0.173	72.251	1.000	-0.621	0.503
	Barefoot-Artificial	-0.233	0.154	75.355	1.000	-0.732	0.266
	Barefoot-Turf	-0.901	0.158	67.945	**0.000**	-1.415	-0.387
	GluShu-Artificial	-0.535	0.165	75.250	0.050	-1.071	-2.392E-05
	GluShu-Turf	-0.609	0.167	71.020	**0.015**	-1.152	-0.065
	Steel-Artificial	0.113	0.157	72.173	1.000	-0.396	0.622

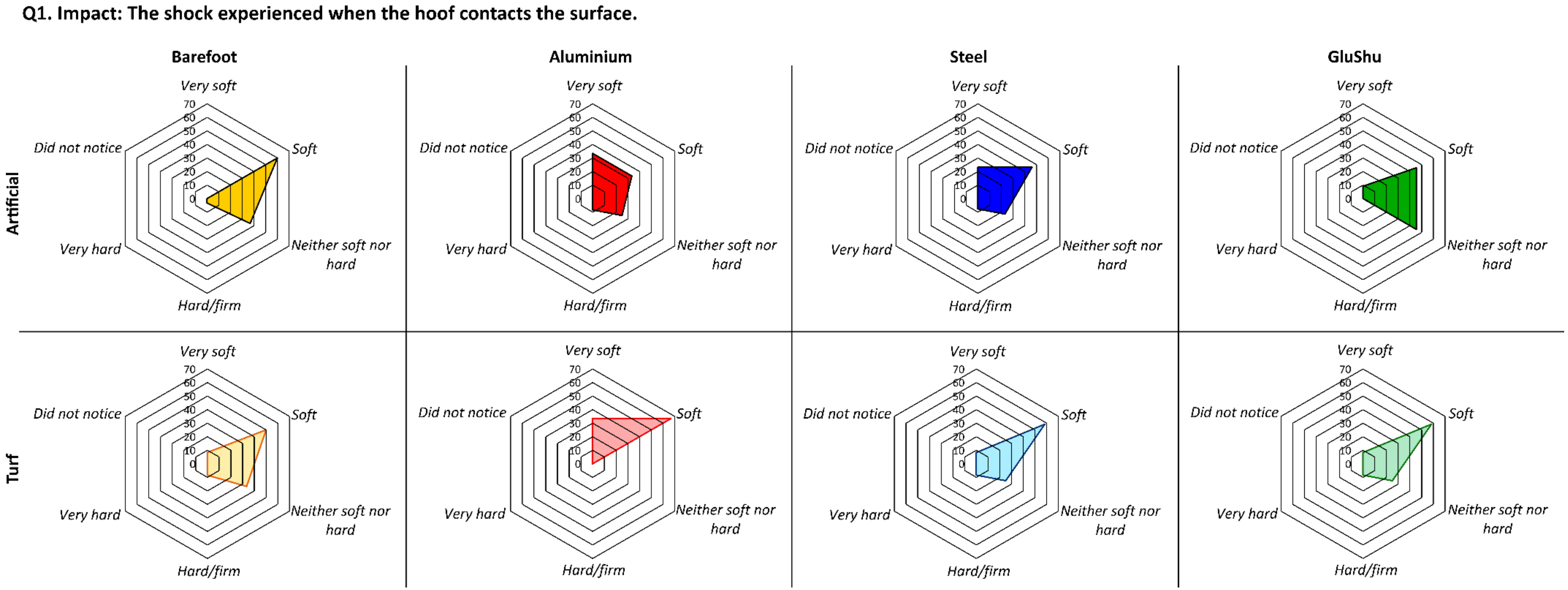

Figure S1 Radar plots illustrating jockey responses to nine questions investigating their experience of eight shoe-surface combinations trialled at gallop. Units are percentages. Continued overleaf.

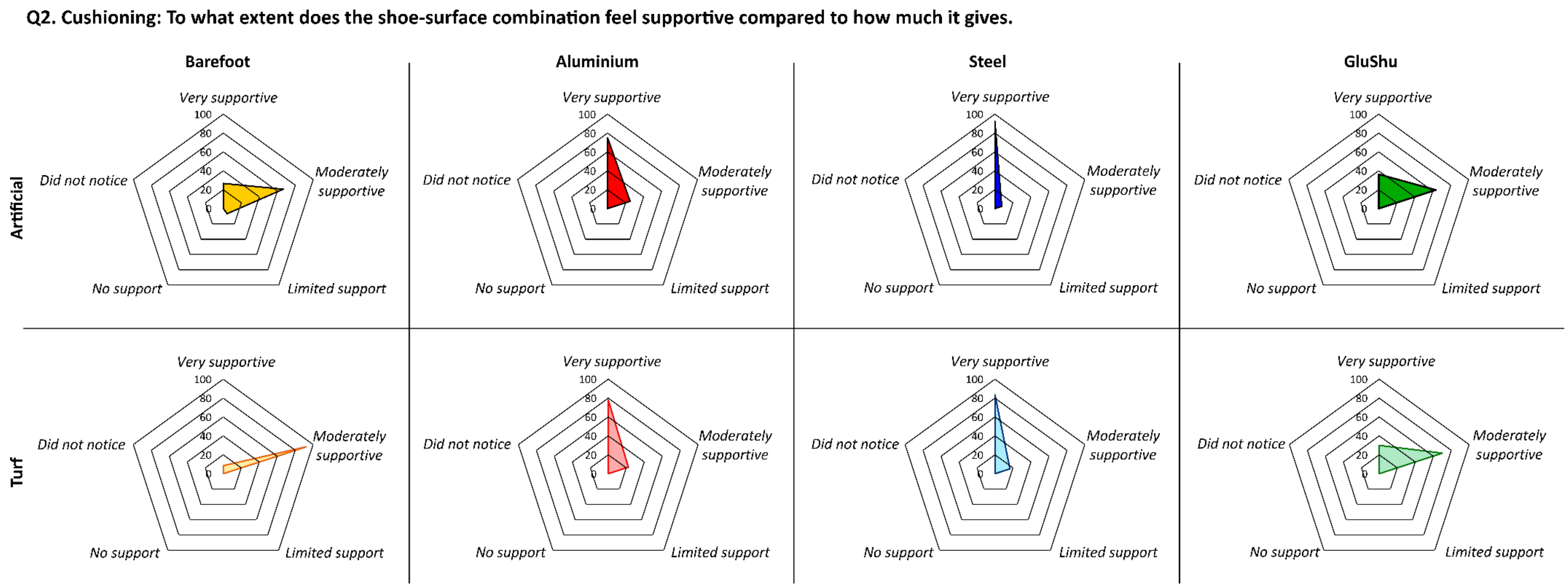

Figure S1 (continued)

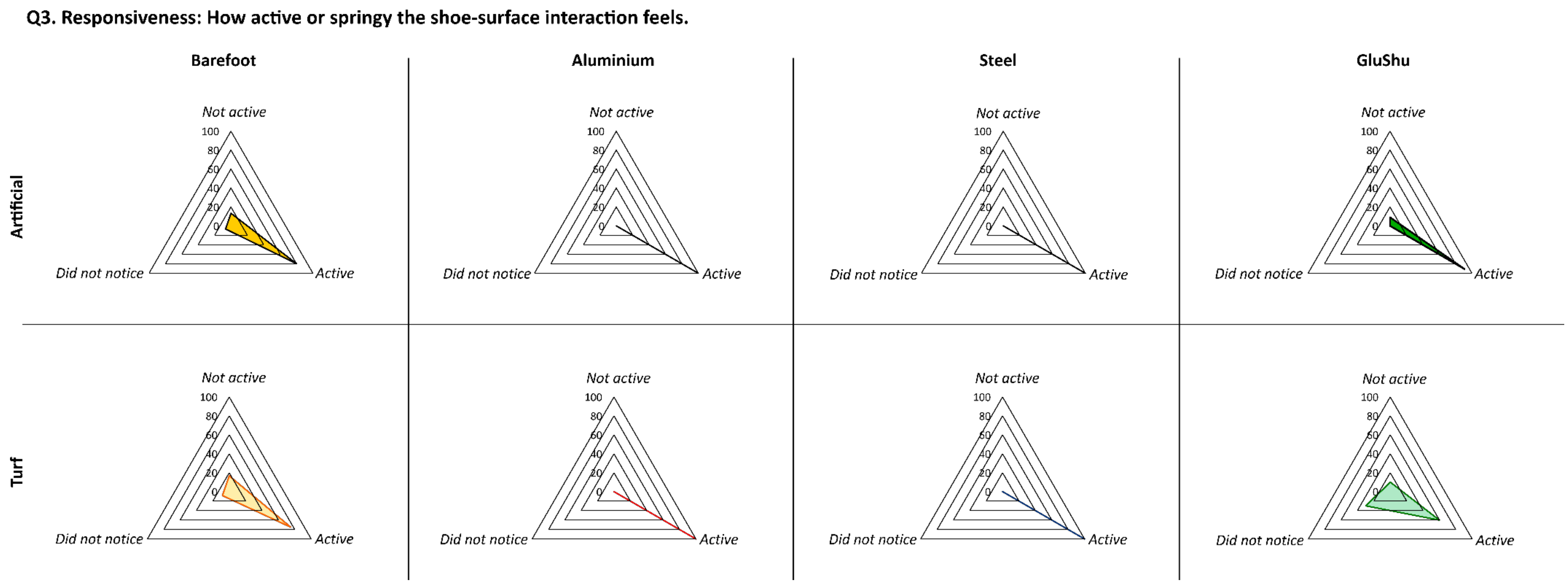

Figure S1 (continued)

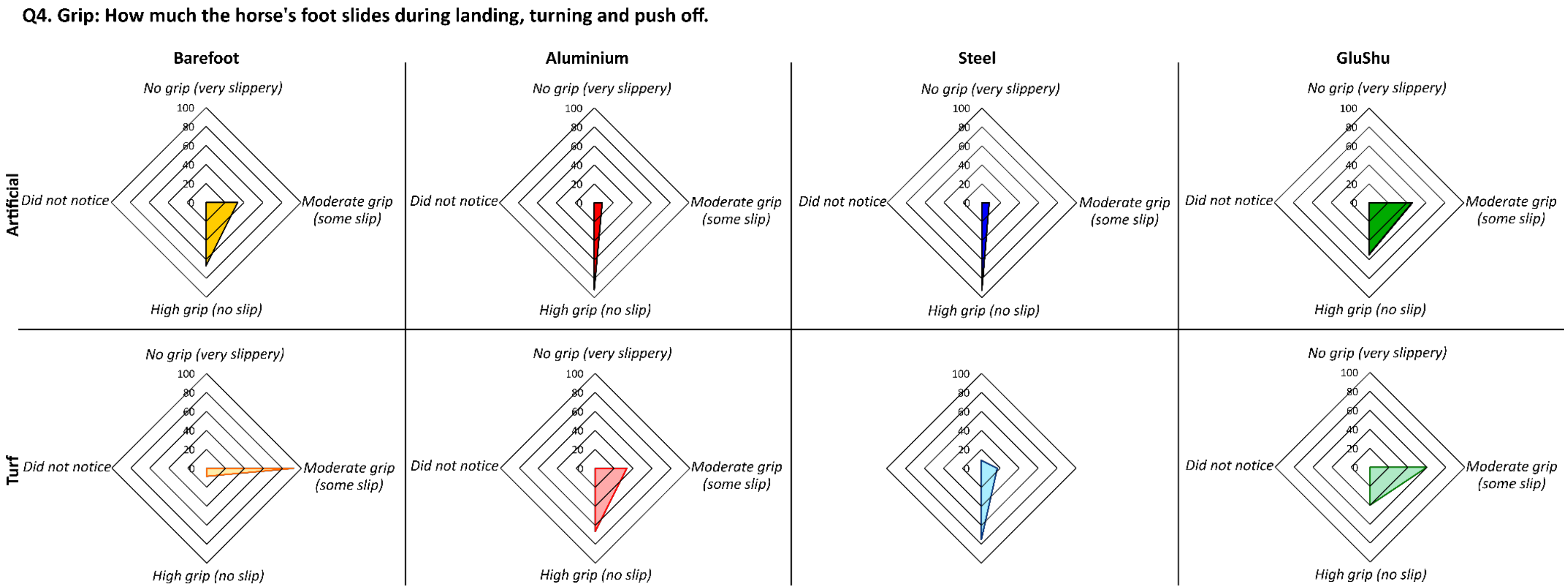

Figure S1 (continued)

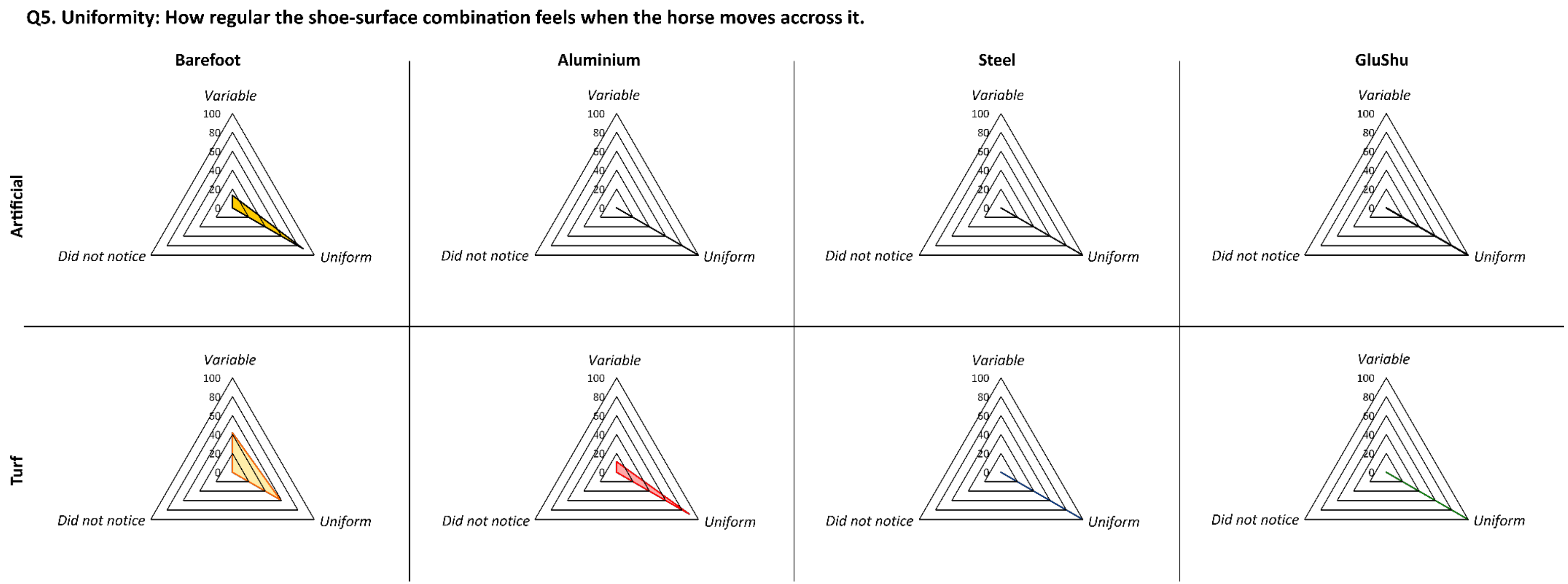

Figure S1 (continued)

Q6. Adaptation period: Time taken to adapt to shoe-surface combination.

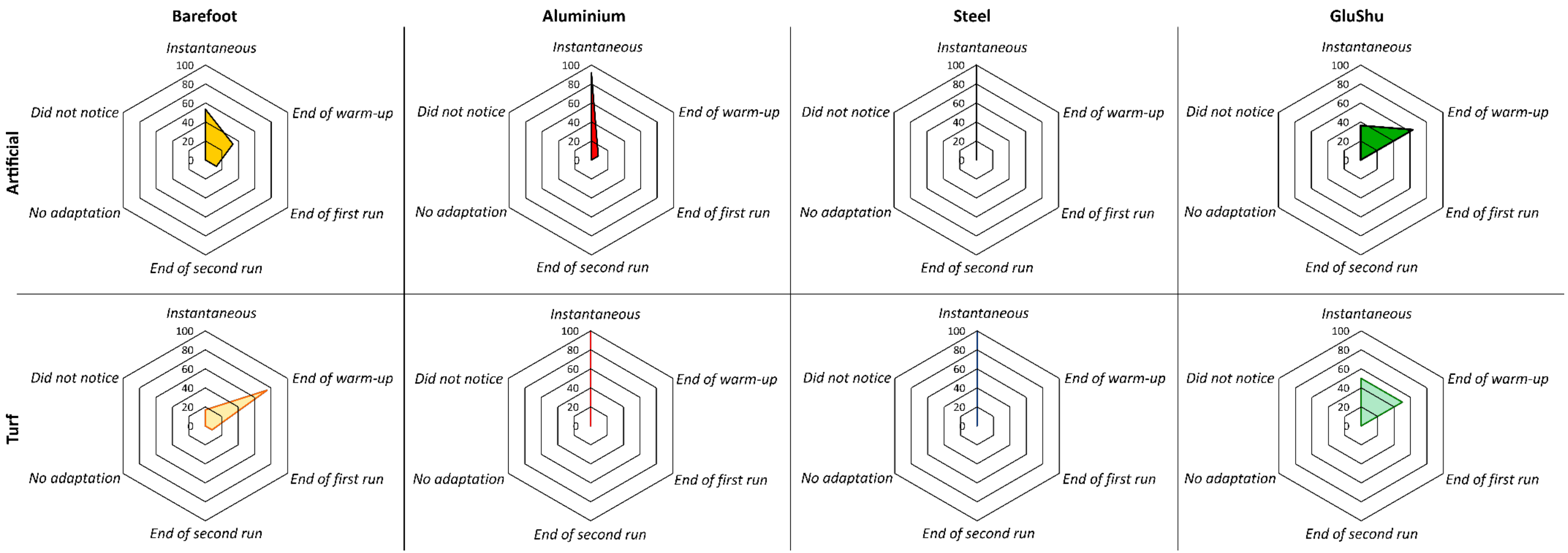

Figure S1 (continued)

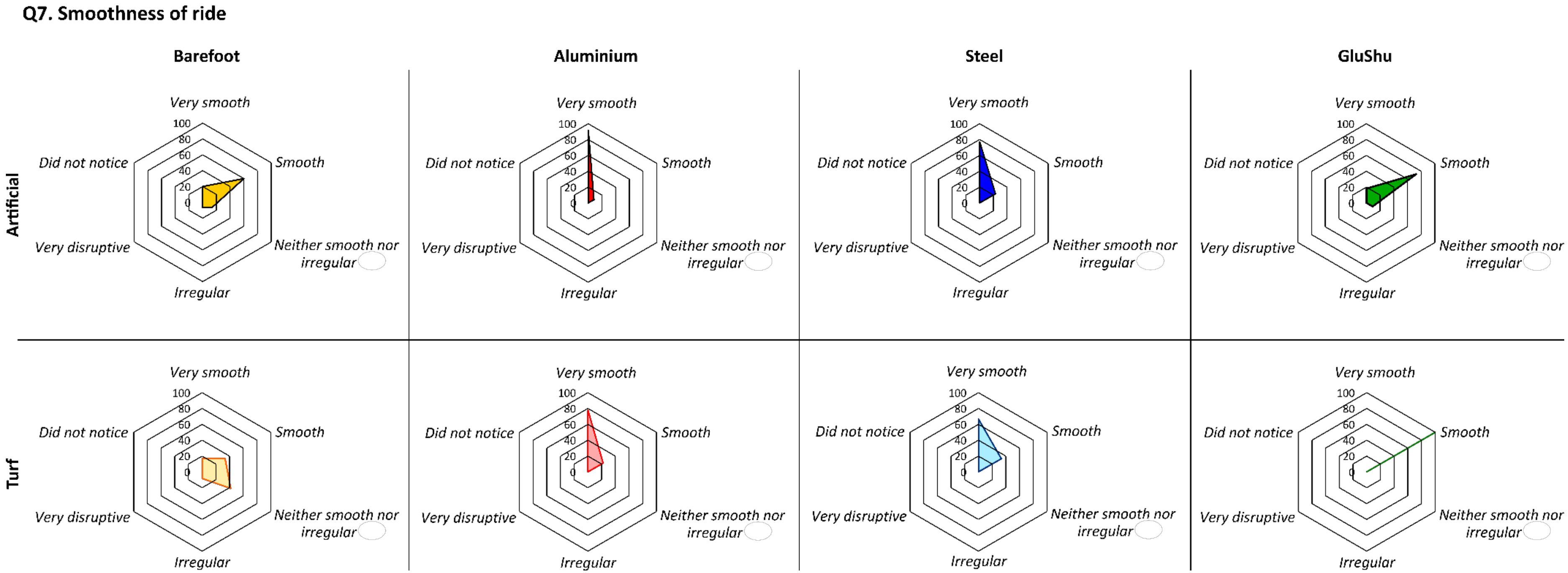

Figure S1 (continued)

Q8. Safety: How safe you felt with the shoe-surface combination.

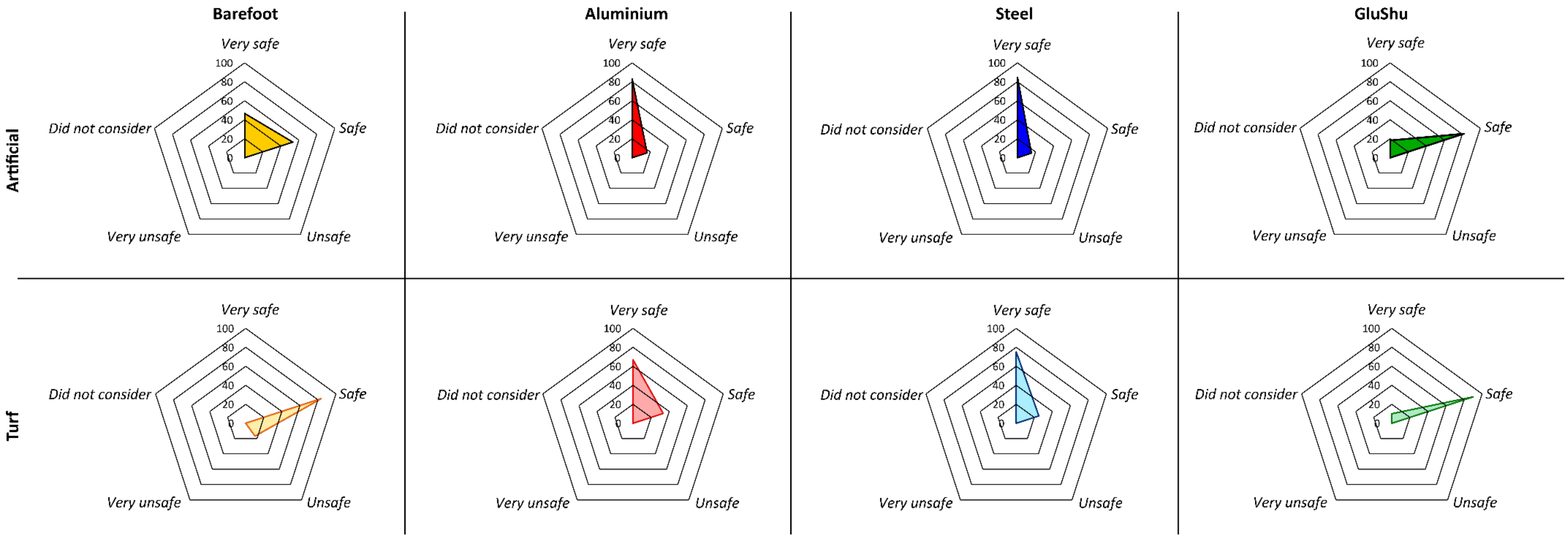

Figure S1 (continued)

Q9. Overall rating: What is your general opinion of the shoe-surface combination?

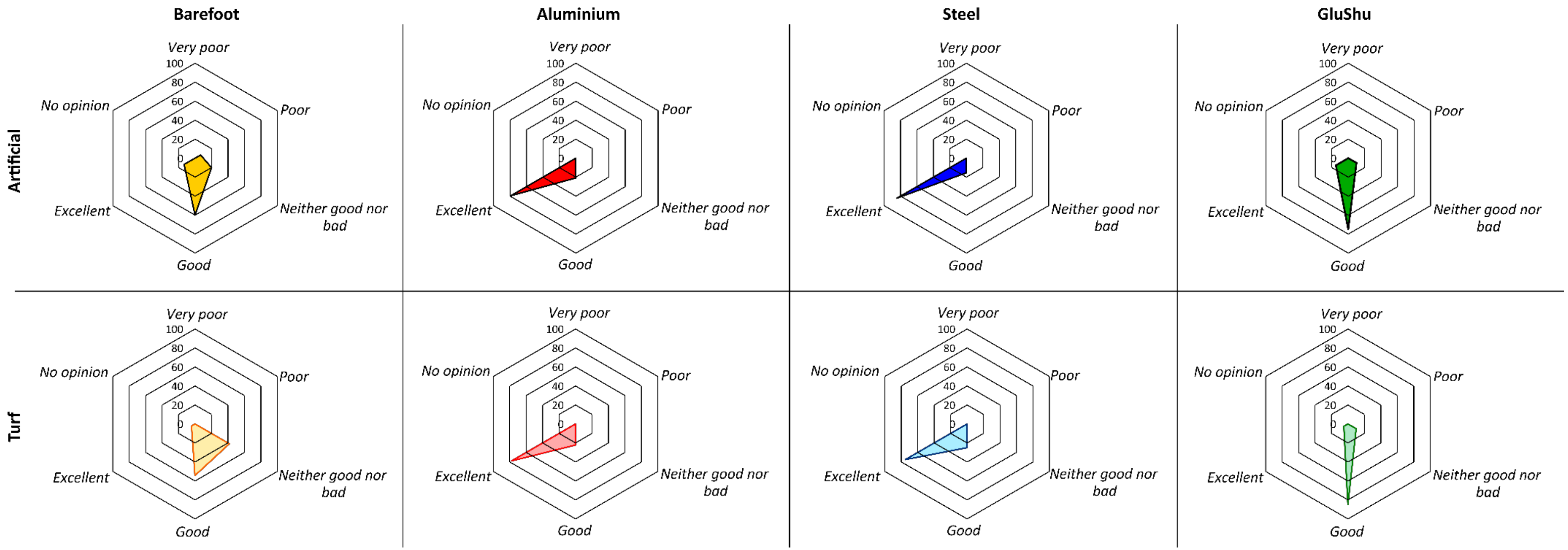

Figure S1 (end)