Comparison of stirrup lengths chosen for flatwork by novice and experienced riders

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Abstract

Although stirrups may be considered an essential part of equestrian equipment, there is little research describing their use and function. The aim of the present study was to compare stirrup lengths chosen for flatwork by novice and experienced riders and to measure the associated leg position and knee angles. Ten novice and ten experienced riders, with kinematic markers attached to their greater trochanter, lateral femoral epicondyle, and lateral fibular malleolus, mounted three horses and a mechanical horse. The riders selected an appropriate stirrup length for flatwork by adjusting the unnumbered stirrup leathers. Stirrup length was measured and expressed as a percentage of the rider's leg length measured from the greater trochanter to the floor when standing. Lateral photographs were taken from both sides with the riders mounted on each horse in a standing position. The kinematic markers were digitised to measure knee angle and ankle position relative to the hip in the anteroposterior direction. Within riders, there was no significant difference in stirrup length between the three live horses or between the mechanical horse and live horse. Experienced riders consistently selected a significantly longer stirrup length as a percentage of their leg length compared with novice riders (combined data for live horses and mechanical horse; P=0.005). Experienced riders demonstrated a significantly larger knee angle (combined data for live horses and mechanical horse) compared with novice riders (118±8° and 109±7°, respectively; P=0.016). Novice riders had a significantly larger knee angle on the mechanical horse compared with the live horse (115±9° versus 107±9°, respectively; P=0.003). The relatively longer stirrup length selected by experienced riders is thought to reflect the development of an independent seat, which implies the ability to move the legs independently of the pelvis. The chair seat adopted by novice riders on the mechanical horse could be considered counter to improving their equitation skills.

Keywords: equestrian, horse, equitation, stirrups, riding

Introduction

Stirrups have been used for at least 2,000 years to improve the rider's balance and stability in the saddle, particularly during warfare. In the intervening years, modifications to stirrup design have occurred to fulfil the needs of different types of riding but, on the whole, stirrups have changed surprisingly little. Today, they are used to support the weight of the rider's legs (Kang et al., 2010) and may convey signals to the horse through the application of stirrup forces. Stirrup length varies greatly between equestrian disciplines being shortest in flat race jockeys, somewhat longer for jumping, and longest in Western, endurance and dressage riders. For general purpose riding, the length of the stirrup is typically intermediate between the lengths used for dressage and jumping. Older equitation manuals suggested adjusting the stirrup leathers so that the bottom of the stirrup was at the level of the medial malleolus (ankle bone) with the leg hanging loosely and the feet out of the stirrups (Reed and Redhead, 1995; The Pony Club, 1993). It has also been suggested that stirrup length can be estimated before mounting by placing the knuckles against the stirrup bar and pulling the stirrup into the armpit (The Pony Club, 1993). Shorter stirrups are associated with greater flexion of the rider's hip, knee and ankle joints (Hyun and Ryew, 2015), which can then act as springs to support the body weight during galloping and jumping where the rider is 'out of the saddle' (i.e. the rider's seat is not in contact with the saddle). Jockeys support most of their body weight in the stirrups and adjust the flexion angles of the hip, knee and ankle joints to absorb the horse's vertical oscillations. This allows the jockey's movements to be uncoupled from those of the horse, which reduces the horse's energy expenditure (Pfau et al., 2009).

Regardless of the style of riding or stirrup length, it is a general principle that, when viewed in the sagittal plane, the rider's ear, shoulder, hip and heel should be aligned vertically (Blokhuis et al., 2008; Sivewright, 1979; Terada et al., 2000). In this position, the vertebrae can conform to the normal spinal curvatures (neutral spine) and the legs fall beneath the rider's centre of mass. Given that individuals vary in the relative lengths of the thigh and shank, it might be expected that stirrup length, limb segment angles and joint angles will vary between riders. If the rider has symmetrical posture and movements, it is thought to facilitate the development of straightness in the horse (Hobbs et al., 2014). However, Hyun and Ryew (2015) found that, in spite of having equal stirrup lengths, the angles of the hip and ankle joints increased more in the right leg than the left when the stirrups were lengthened. It has also been reported that the right hip shows more external rotation than the left during riding (Gandy et al., 2014). Inequality of leg lengths has been related to thoracic girdle rotation away from the shorter leg (Symes and Ellis, 2009).

During locomotion, the movements of the horse drive the movements of the rider (Von Peinen et al., 2009) causing segmental kinematics to change. Over a prolonged period of time riders learn to maintain their posture in the face of perturbations due to gravitational, inertial and ground reaction forces. Therefore, experienced riders are expected to have better postural control during riding and to maintain a position that is closer to the ideal alignment compared with novices. This has been supported by studies comparing kinematics of riders with different levels of experience. In walk, sitting trot and rising trot, experienced riders were distinguished by having significantly greater hip extension, with the contributions of trunk angle and thigh angle varying by gait. Knee angle did not differ between riders with different levels of experience but the lower leg was positioned further posteriorly under the body in experienced riders (Schils et al., 1993). The rider's movement pattern also becomes more consistent with experience (Lagarde et al., 2005; Peham et al., 2001). For example, the knee joint undergoes a smaller range of motion in sitting trot in more experienced riders (Eckardt and Witte, 2016).

Stirrup length affects the position and movements of the rider's leg, with shorter stirrups compressing the hip, knee and ankle joint angles (Hyun and Ryew, 2014). The authors are not aware of published data describing the stirrup lengths selected by riders with different skill levels or whether riders choose to adjust the stirrups to equal lengths on the left and right sides. This study investigates and compares self-selected stirrup lengths for riding on the flat in novice and experienced riders, and if stirrup length selection differs between live horses and a mechanical horse. The experimental hypotheses are, firstly, that experienced riders will select a longer stirrup length relative to their standing leg length compared with novice riders and, secondly, that all riders will adjust their stirrups lengths equally on the left and right sides. Stirrup length was hypothesised to remain consistent regardless of which horse: live or mechanical they were riding.

Materials and methods

Riders

The study compared two groups of ten female riders: novice and experienced. The novice group comprised inexperienced riders selected after being assessed for a UK level three equine college course which resulted in categorisation into groups with high, average and low ability levels. The subjects for this study were selected from the low ability group. The experienced riders were all selected from staff and students at the college who held a minimum BHS Stage III riding qualification, which has been used previously as an indicator of ability (Lovett et al., 2005). It requires a rider to show a secure, supple, independent and balanced position.

For data collection, riders were instructed to wear plain coloured breeches, long boots, protective hats and gloves. All participants were given an information sheet about the study and signed a consent form. Riders under 18 years of age were required to obtain parental consent.

Horses

Three riding school horses that were judged suitable for the study by a qualified instructor were used. All horses were in regular work for around 2 h per day, 6 days per week giving riding lessons. During the study the horses wore the saddle they normally used for lessons (Table 1). For each saddle, the length was measured from pommel to cantle and the width was measured between the nail heads (also known as rivets) on left and right sides. Each horse wore a set of tack that was fitted and regularly checked by equestrian centre instructors.

A pair of un-numbered stirrup leathers, with the holes at equal lengths and at 2.54 cm intervals on the left and right leathers, were fitted to each saddle so that riders would not select stirrup lengths based on a numbered hole. Riders also mounted a mechanical horse (Racewood Canter Simulator, Racewood Ltd., Tarporley, Cheshire, UK) wearing the same saddle as horse 1. Using custom-made wooden callipers, the live horses' chest widths were measured at the widest part

Table 1. Horse and saddle characteristics.

	Height (m)	**Horse chest width (cm)**	**Breed/type**	**Age**	**Saddle type**	**Saddle length (cm)**	**Saddle width (cm)**
Horse 1	1.57	64.8	Cob	18	Kent and Masters GP	43	44
Horse 2	1.57	58.2	Thoroughbred	13	Barnsby GP	43	37
Horse 3	1.60	64.9	Irish Cob	12	Ideal GP	41	46
Mechanical horse	1.43	58.2	Racewood Canter Simulator	NA	Kent and Masters GP[2]	43	44

[1] Saddle length was measured from nail head to the middle of the cantle; saddle width was measured across the front from nail head to nail head (also known as rivets).

[2] Same as saddle used on Horse 1.

Data collection

In order to permit measurements from identifiable anatomical landmarks on the riders, white 2.5 cm hemispherical polystyrene balls were secured to the rider with double-sided tape by the same experienced experimenter for both data collection days. Markers were positioned over the greater trochanter of the femur, the lateral epicondyle of the femur and the lateral malleolus of the fibula in accordance with the methods used by Lovett et al. (2005) and Schils et al. (1993).

In a small indoor school (20 × 40 m), riders mounted the live horses from a mounting block using the left stirrup. After mounting the saddle position was checked by an experienced riding instructor to confirm it was located centrally on the horse's back. The riders were instructed to adjust their stirrups for a flat work session which included using unmounted methods to estimate stirrup length. After adjusting the stirrups, they walked a half circuit around the school and halt squarely at a marked point on the track where they were given the opportunity to adjust their stirrup length. A Samsung® ST150F HD digital camera (Samsung, Sheffield, UK) was mounted at a height of 1.3 m on a tripod with an integrated levelling device that ensured the camera was horizontal (Hama® Star 61, Hama Ltd., Basingstoke, UK). This camera height was chosen so that the rider's leg was in the central area of the field of view for both live and mechanical horses to avoid perspective errors in the linear measurements. The camera was placed 3.5 m from, and perpendicular to, the track at the point where the horses halted. Riders were given an opportunity to adjust their stirrup length before photographs were taken. An image was taken of the left side of the horse and rider. The rider was instructed to walk forwards, turn the horse and re-position it at the same marker on the track but facing in the opposite direction. An image of the right side of horse and rider was then taken. The stirrup holes selected by the rider on the left and right were recorded, counting from the end of the leather toward the buckle (so a higher number indicated a shorter stirrup). With the markers still in place, riders rotated around the three horses according to a randomised order and repeated the procedure of adjusting the stirrups, then taking images and measurements.

On a different day, the saddle from horse 1 was fitted to the mechanical horse. This saddle was assessed by the researchers as being the 'best fit' for the mechanical horse. Markers were applied to the riders as for the live horse session. Riders mounted the mechanical horse from the left side and were instructed to adjust their stirrups for a flat work session. After a short warm-up the saddle position was checked and the riders were given the opportunity to adjust their stirrup length. Images and measurements were taken from left side of the mechanical horse using the same procedure as for the live horse sessions, then the camera and tripod were relocated to the right-hand side of the mechanical horse to obtain the second image.

On another day, riders were instructed to wear the same clothes as for the ridden sessions, and the same marker set was applied by the same researcher. The following measurements were made: rider height (in boots), rider weight (dressed), and height of the rider's greater trochanter above the ground. For each rider the entire data collection was completed within 4 weeks and none of the subjects experienced an injury or illness during that time.

Data analysis

Image J (National Institutes of Health, Bethesda, MD, USA) was used to calculate left and right knee angles on the posterior aspect of the joint from the photographs of the riders mounted on the live horses and the mechanical horse. The orientation of a line connecting the hip and ankle markers relative to a vertical line through the hip was measured when riders were mounted on Horse 1 and the mechanical horse. Positive angles indicate that the line from hip to ankle lay ahead of (anterior to) the vertical (Figure 1).

The hole numbers on the stirrup leathers were converted to length measurements by placing the saddle on a wooden saddle stand and measuring from the top of the buckle to the top of the stirrup tread (where the foot would sit). This was repeated for every hole of the left and right stirrups on each saddle. This measurement will be referred to as stirrup length. The stirrup lengths for each rider on left and right sides were expressed as a percentage of the riders left and right leg lengths, respectively, which were measured from the greater trochanter to the floor (rider standing, unmounted). Normalisation of stirrup length to leg length facilitates comparisons between riders of different heights and leg lengths.

Statistics

The Kolmogorov Smirnov test was applied to the data to determine whether the data were parametric or nonparametric. All data approximated a normal distribution and therefore parametric methods were used. The effect of horse (live horses and mechanical horse combined) and rider experience on stirrup length selected and knee angle were investigated using a two-way ANOVAs. Differences in leg length, angle to the vertical, knee and hip angles between novice and experienced riders were investigated using two-tailed unpaired t-tests. Further two-tailed paired t-tests established if differences occurred between right and left stirrup length expressed as a percentage of leg length for the novice and experienced rider groups, and if the mean stirrup length varied between the live horses and mechanical horse. All analyses were carried out in SPSS (SPSS Statistical software version 22, IBM, Armonk, New York, USA). Data are presented as mean ± standard deviation. Significance was set at $P<0.05$.

Results

Figure 1. Images of a novice riders on horse 1 (left column) and mechanical horse (right column) illustrating the lines drawn to calculate the position of the ankle relative to the hip and showing the differences in the riders' positions on the live horse versus the mechanical horse. The line joins the pommel to the cantle and indicates the tilt of the saddle.

Details of the horses (height, chest width, breed) and saddles (type, length, width) are shown in Table 1. There were no significant differences in the weight or height between novice (mean ± standard deviation: weight: 62±9 kg; height: 163±6 cm) and experienced riders (weight 61±6 kg: height 168±6 cm), but experienced riders were older (novice: age 16±1 years; experienced: age 29±6 years). Leg lengths did not differ significantly within either group or between novice (left leg length: 90.1±2.7 cm; right leg length: 90.4±3.1 cm) and experienced (left leg length: 90.7±5.5 cm; right leg length: 90.7±4.8 cm) riders (P>0.05).

Stirrup length expressed as a percentage of leg length (SL%LL) did not differ significantly between the left and right sides for experienced riders (P>0.05), however, a significant lateral difference did exist for novice riders with their right stirrup length on average 2% longer than their left (P=0.0001). Two-way ANOVA analysis found no significant interaction between horses or rider experience and stirrup length selected (P>0.05). The stirrup length chosen by riders was also not influenced by horse selection, live or mechanical (P>0.05). Experience did affect lengths, with experienced riders' consistently selecting significantly longer stirrups than novice riders (left P=0.0001; right P=0.0001; Table 2).

The angle between the line from ankle to hip and the vertical (Figure 1) was positive for all riders on all horses (indicating the ankle was anterior to the hip) with the exception of one novice rider on horse 1 (-5.7°). There was no difference between novice and experienced riders on horse 1 (P>0.05) or between experienced riders mounted on horse 1 and the mechanical horse (P>0.05; Figure 2). Novice riders, however, placed their ankle at a significantly greater angle ahead of the vertical on the mechanical horse compared with on horse 1 (12.1±4.7° versus 5.3±6.1°; P=0.013) (Figure 2). Two-way ANOVA analysis found no interaction between horses or rider experience (P>0.05). Rider experience was influential, with novice riders recording decreased angles compared to their experienced peers (Left: P=0.03; Right: P=0.0001). There was no effect of horse on ankle to hip angles (P>0.05).

When data for live horses and the mechanical horse were combined, knee angles were significantly larger in experienced riders compared with novice riders (118±8° and 109±7°, respectively; P=0.0162) (Table 3). Left and right knee angles did not differ significantly in either novice or experienced riders (P>0.05). Knee angles were not significantly different between the three live horses for novice or experienced riders (Table 3). Comparing knee angles for riders mounted on horse 1 versus the mechanical horse wearing the same saddle, experienced riders showed no significant difference (P>0.05), but novice riders had significantly larger (more extended) knee angles on the mechanical horse than on horse 1 (115±9° versus 107±9°, respectively; P=0.0029) (Figure 2).

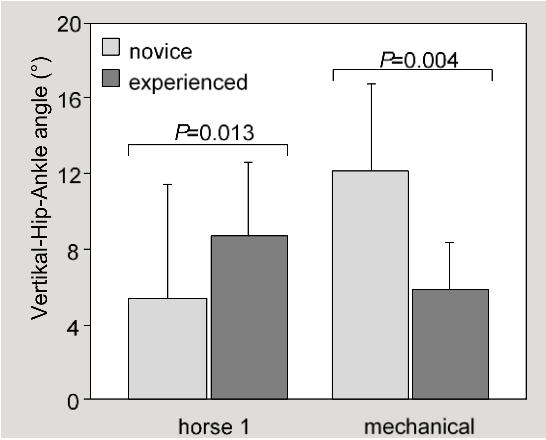

Figure 2. Angle between the vertical and line connecting the hip to the ankle in novice (grey bars) and experienced riders (black bars) on Horse 1 and the mechanical horse.

Table 2. Stirrup length (SL) in centimetres expressed as a percentage of leg length measured from hip to floor in novice (n=10) and experienced (n=10) riders on three live horses (horses 1, 2 and 3) and on a mechanical horse. Values are mean ± standard deviation.

	Stirrup length (% leg length)	**Horse 1**	**Horse 2**	**Horse 3**	**Mean (3 horses)[1]**	**Mechanical horse**	**Mean combined horses**
Novice	left	70±4	69±4	72±4	70±3	69±4	70±3
	right	73±4	70±4	72±4	71±4	72±4	71±4
	mean	71±4	70±4	72±4	71±4*	70±4	71±4
Experienced	left	76±5	74±4	76±4	75±3	75±4	75±3
	right	76±2	75±3	74±2	75±2	76±2	75±2
	mean	76±3	74±3	75±3	75±3*	76±3	75±3

[1] Experienced riders significantly different from novice riders indicated by an asterisk (*P*=0.005).

Discussion

The study has three main findings. Firstly, experienced riders select a longer stirrup length relative to their leg length than novice riders, which supports the first experimental hypothesis and is consistent with anecdotal observations. Secondly, experienced but not novice riders adjusted their stirrups symmetrically on the left and right sides, which partially supports the second experimental hypothesis. Thirdly, in spite of having the same stirrup lengths on horse 1 and the mechanical horse, novice riders sat with their legs further forward and their knee joints more extended on the mechanical horse compared with in the same saddle on a live horse, which was an unanticipated finding.

Balance is a complex function in which posture is maintained by interactions between the neurological and musculoskeletal systems (Kim et al., 2014). In equestrian sports, balance is regarded as a skill-related component of fitness that is dependent on good core strength to stabilise the rider's position (Hampson and Randle, 2017). Novice riders are likely to have weaker core muscles and their coordination during riding is inferior compared to more experienced riders. In the study reported here, the selection of longer stirrup lengths by the more experienced riders is indicative of the development of an 'independent seat' which implies an ability to move the arms and legs independently of the pelvis and trunk.

The leg has three articulated segments, the thigh, shank and foot, each with its own mass and inertial properties. Adjacent segments are connected by the flexible hip, knee and ankle joints, the movements of which are driven by the neuromuscular system. The orientation of the rider's leg is determined by the interaction between the force of gravity, the mechanical properties of the segment, and the neuromuscular forces. Proprioceptive and tactile inputs contribute to determining the segmental orientations with respect to each other and the external world (Suetterlin and Sayer, 2013). Experienced riders selected equal lengths in the left and right stirrups, adjusted their stirrups to the same length relative to leg length and had the same knee angles on three live horses and a mechanical horse, which is indicative of good proprioceptive awareness and shows the development of an accurate internal representation of their leg geometry. Novice riders apparently did not have such a good proprioceptive awareness as indicated by the significantly longer right stirrup under all conditions and the adoption of a different position on the mechanical horse with the ankle further ahead of the vertical and a larger (more extended) knee angle. Apparently, the novice riders were influenced more by the slightly different balance of the saddle on the mechanical horse, whereas experienced riders maintained a correct body alignment regardless off saddle position.

Throughout their equestrian career, riders are taught that the correct leg position aligns the heel vertically below the hip, with the angulations of the intervening joints compressing or extending to accommodate different stirrup lengths (Hyun and Ryew, 2015). With practise and through the development of muscle memory this becomes a reproducible posture that serves as a reference position that the rider returns to after being perturbed by the movements of the horse. As the rider develops an independent seat, the stirrups are lengthened. The longer stirrup length chosen by the more experienced riders likely reflects an advanced level of muscular coordination and postural control within the riding position. Experienced dressage riders have been shown to ride with a greater posterior pelvic tilt compared with novices (Münz et al., 2014), and the degree of pelvic tilt increases with collection (Byström et al., 2015; Engell et al., 2016). The posterior pelvic tilt is combined with retraction of the thigh resulting in a more extended hip joint, which has been identified as a trait of experienced riders (Schils et al., 1993) and is likely a consequence of selecting a longer stirrup length. The fact that knee angle did not differ between novice and experienced riders has been reported previously (Schils et al., 1993). The ability to ride with a longer stirrup length may also be protective against the development of back pain because shorter stirrups are associated with a more horizontal position of the thigh that flattens or decreases the natural lumbar lordosis. Consequently, the back loses some of its inherent capacity to absorb the motion of the horse (Quinn and Bird, 1996). However, consideration of the causes of back pain in riders is beyond the scope of this study.

Studies of rider kinematics and kinetics have shown some consistent asymmetries within the groups of riders tested. Alexander et al. (2015) reported that a majority of riders presented with the pelvis tilted lower on the right and rotated further posteriorly on the right. The trunk had a compensatory left lateral tilt but was also twisted to the right. Similarly, Kang et al. (2010) found that novice riders had their pelvis tilted down to the right. If the pelvis is lower on the right side, it could explain the longer right stirrup length chosen by the novice riders in our study. In addition to the pelvic asymmetries, the right hip was significantly more externally rotated than the left hip while riding (Gandy et al., 2014). Although the authors did not further investigate the cause or effects, an illustration in the paper shows a lower position of the right foot in a subject with greater external rotation of the right hip. Another study found that the hip and ankle joints were more extended in the right leg than the left leg when riding at a longer stirrup length (Hyun and Ryew, 2015). The possibility of a relationship between the positional asymmetries and the rider's handedness pattern has not yet been investigated.

The difference in the novice riders' leg position on the live horses versus the mechanical horse in spite of having the same stirrup length is an interesting finding. The photographs (Figure 1) show the typical position of a novice rider on the mechanical horse with the seat further back on the saddle and their legs pushed forwards, which is typically described as a 'chair seat'. The fact that the experienced riders did not adopt a chair seat may indicate greater versatility in coping with horses and saddles of different shapes and sizes. For novice riders it is important to facilitate learning of correct kinematics and the position of these riders on the mechanical horse in this study would be counter-productive in achieving this goal. It appears that saddle balance on the mechanical horse is an important consideration in optimising the learning experience.

Conclusions

Riders with different levels of experience showed consistency in selection of their stirrup length relative to their leg length when mounted on different live horses and a mechanical horse. They also demonstrated an ability to adjust left and right stirrups to the same length simply by feel (without the cue of a numbered stirrup leather). Experienced riders consistently selected a longer stirrup length than novices. The fact that novice riders adopted a chair seat on the mechanical horse draws attention to the need for careful observation when using a mechanical horse to ensure that the saddle fits appropriately and helps the rider to learn correct posture and technique.

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