The effects of using a specially designed stirrup on kinetic energy absorption by the knee joint of 12 show jumping or eventing riders.

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Key points:
The use of Winderen Knee Protect Solution stirrups compared to standard iron stirrups, reveals the following benefits:

- a reduction of stress or strain time in the order of 14 seconds per minute of activity whilst walking and 5-7 seconds less whilst trotting or cantering for muscles around the knee.
- a reduction of stress or strain time in the order of 25 seconds per minute of activity whilst walking and 9-10 seconds less whilst trotting or cantering for ligaments around the knee.
- a significant improvement in the E-score (less time exposed to stress and shock) and ST-score (lower force around the knee) whilst walking.
- a considerable improvement in rider comfort and feeling of leg stability (self-assessment) compared with the owners current stirrups, whilst riding.

Introduction:
Equestrian sport is one of a kind, where rider's legs play a key role in communication with the horse, as well as ensuring the rider maintains body balance whilst in the saddle. Rider's legs work hard to keep the rider in an optimal saddle position, and they need to withstand a lot of force - coming mainly from the dynamic interactions with the ground and the horse while riding. These forces are rather exceptional for equestrian sport, and are otherwise rarely experienced in "normal", daily activities – the closest one comes to such bent knee physical exertion is during squats. It is especially the knee joints of riders that experience considerable and repeated loading, being responsible for a good deal of shock absorption. A number of professional riders, who ride 6-8 horses on a daily basis, often experience knee pain (Lewis et al., 2018). This discomfort is also experienced by less experienced riders, who have yet to attain a well-trained balance whilst in the saddle, as well as taller riders, who might experience greater forces around the knee joint.

Use of comfortable, innovative solutions is not only of benefit for riders, it also benefits their horses. Correct placement of the leg in the stirrups and the mechanical properties of shock absorption by the stirrups are believed to ensure knee protection and provide a stable seat. Improved shock absorption can also be expected to reduce both overuse injuries and associated pain, ultimately protecting the horse from a rider's asymmetrical "guarding" style of riding, which they may have adopted in order to try and avoid injury.

The aim of this trial project was to test the efficiency of stirrups designed for their shock absorbing properties as measured using acoustic myography (AMG) in 12 healthy equestrian athletes while riding in symmetrical and asymmetrical gaits.

Hypotheses:

1) Winderen Knee Protect Solution stirrups reduce the amplitude of the AMG signal around the knee joint of riders at low speeds and low levels of riding activity compared with standard iron stirrups.

2) At high levels of riding activity the Winderen Knee Protect Solution stirrups reduce the time duration of loading forces around the knee joint of riders when compared with standard iron stirrups.

Materials and methods:
Ethical Approval: The method applied was non-invasive, and the trial project followed the guidelines set by the Helsinki Declaration 2013 (http://www.wma.net/en/30publications/10policies/b3/).

Subjects: Twelve healthy and experienced riders (11 female; 1 male), who were in regular training (minimum of 5 times a week for at least 1 hour) were recruited at random for this trial project from riding schools in an around the Copenhagen area. The average weight of the riders was 59.9 ± 7.7 kg and they were aged 31.2 ± 13.0 years (range 13-55). The riders were asked to state any knee related injuries or pain, and to identify which leg was affected, and if found to have an injury or pain, that leg was selected for measurement.

Measurements: Measurements from two key anatomic structures, responsible for knee joint amortization in a riding position, namely the patellar ligament (also referred to as the patellar tendon) and the vastus lateralis muscle (lateral head of quadriceps femoris muscle) were selected for this trial project.

Methodology: Acoustic Myography (AMG), which has proven to be non-invasive, facilitating a real-time monitoring of muscle and ligament activity, as well as enabling the assessment of physical performance during exercise (e.g. cycling, jogging, horse riding) was used. Acoustic myography (AMG) is a biomechanical method measuring generated pressure waves from a contracting muscle or connective tissue (Harrison, 2018),(Claudel et al., 2018).

This trial project measured each of the riders during periods of walk, trot and canter, as well as monitoring a few selected riders whilst jumping. Initially, the riders own standard iron stirrups were used for a baseline measurement of the three (4) gaits, and thereafter the standard stirrups were exchanged for the Winderen Knee Protect Solution stirrups. Winderen Knee Protect Solution stirrups have been designed with a double shock absorption system, detailed on their website (https://www.winderen.com/en/news/92/technology-that-supports-muscles-and-joints.html). In one instance, where a rider was already using the Winderen Knee Protect Solution stirrups, these were exchanged for another riders standard iron stirrups, and the riders own Winderen Knee Protect Solution stirrups, replaced with a set of identical stirrups supplied by the manufacturer for the purposes of this trial project. This was done to avoid any difference that might occur between a new and used set of Winderen Knee Protect Solution stirrups.

AMG recordings were carried out with a CURO unit and CURO sensors (CURO-Diagnostics ApS, Denmark; formerly MyoDynamik ApS) and followed in real time on an iPhone (Apple Inc, Cupertino, CA, USA) via the App "CURO Equine" and a specialized data recording system. This allowed us to see the actual wave recordings and the ESTi score while recording. We used one 50mm and one 20mm sensor with a frequency recording range of 0.5-20±0.5 kHz, for the muscle and ligament, respectively. Sensors were held in place on the skin above the tissue of interest using a hydrogel patch (M863X-T; R&D Medical Products Inc, USA). The sampling rate was 4 kHz. Recorded data were stored to the CURO unit and after completion of measurements transferred to the CURO software for analysis (https://app.myodynamik.com).
The ESTi-score with its three components: 1) efficiency (E-score) 2) spatial fiber recruitment (S-score), and 3) temporal fiber recruitment (T-score) was calculated using the company software (Harrison, 2018),(Claudel et al., 2018). A high value close to 10 represents a good signal, and conversely one that is close to zero, a poor signal. Thus an S-score of 8 represents a signal with a very small amplitude (approx. 0.3 V) and indicates a very efficient use of the muscle. The E- and T-scores were calculated in a similar way, also using a score scale from 0-10, where for the E-score a value of 0 represents constant activity and 10 no activity, and for the T-score a high value indicates an efficient use of the fibers, and a low value muscle fibers that are working hard.

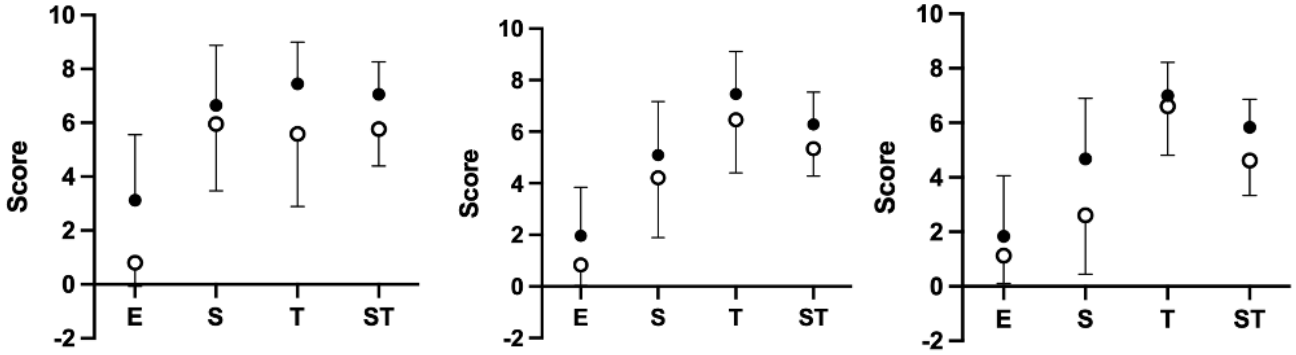
Statistical analysis: Data were analyzed for statistical significance using standard tests (ANOVA; *t*-tests), and a level of significance of 5% ($P<0.05$) was adopted (GraphPad Prism, Version 9.4).

Results:
The riders had a mean riding experience rating of 3.3 ± 0.9, where 1 represents a low level of experience and 4 is a very experienced rider (range 1 to 4).

For placement of the sensors on the legs of the subjects, see figure 1:

Figure 1. Placement of the 50mm and 20mm AMG sensors on the muscle and ligament of the rider's leg.

The AMG data for the muscle vastus lateralis at the walk, trot and canter can be seen in figures 2, 3 and 4, respectively.

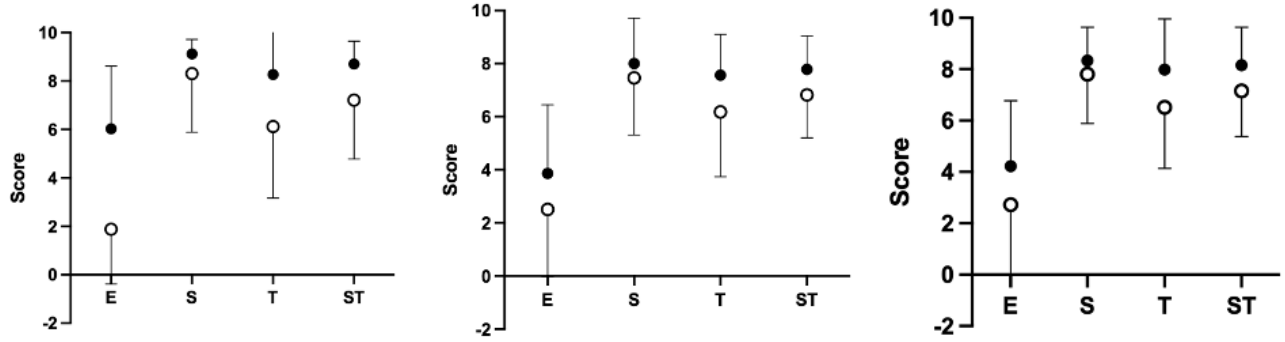


Figures 2, 3 and 4 – m.vastus lateralis walk, trot and canter

It should be noted that in general these activities result in relatively low E-scores compared with the S- and T-scores. Moreover, the use of Winderen Knee Protect Solution stirrups results in higher scores for all 4 parameters (see figures where closed symbols are Winderen Knee Protect Solution stirrups and open symbols are standard iron stirrups). For figure 2 - vastus lateralis at the walk, there was a statistically significant difference for the E- score (P=0.03), T-score (P=0.05) and ST- scores (P=0.03), with Winderen Knee Protect Solution stirrups giving better scores. This study found a 289% improvement in the E-score, a 33% improvement in the T-score and a 22% improvement in the ST-score when using a set of Winderen Knee Protect Solution stirrups compared with standard iron stirrups.

For figures 3 and 4 - vastus lateralis at the trot and canter, no statistically significant differences were noted for any of the parameters whilst trotting, but for the canter both the S-score and the ST-score were significantly improved with the Winderen Knee Protect Solution stirrups (P=0.008 and P=0.01, respectively) compared with standard iron stirrups. It is worth noting that similar improvements to those found during walking were noted: trot: 137% improvement in the E-score, a 15% improvement in the T-score and a 17% improvement in the ST-score; canter: 54% improvement in the E-score, a 22% improvement in the T-score and a 14% improvement in the ST-score.

The AMG data for the patellar ligament at the walk, trot and canter can be seen in figures 5, 6 and 7, respectively.



Figures 5, 6 and 7 – patellar ligament walk, trot and canter

As with the muscle, the patellar ligament measurements show relatively low E-scores compared with the S- and T-scores. Likewise, the use of Winderen Knee Protect Solution stirrups results in higher scores for all 4 parameters. For figure 5 – patellar ligament at the walk, there was a statistically significant difference for the E-score (P=0.007) and the T-score (P=0.05), with Winderen Knee Protect Solution stirrups giving better scores. This study found a 220% improvement in the E-score, a 35% improvement in the T-score and a 20% improvement in the ST-score when using a set of Winderen Knee Protect Solution stirrups compared with standard iron stirrups.

For figures 6 and 7 – patellar ligament at the trot and canter, no statistically significant differences were noted for any of the parameters. However, it is worth noting that similar improvements to those found during walking were noted: trot: 54% improvement in the E-score, a 22% improvement in the T-score and a 14% improvement in the ST-score; canter: 55% improvement in the E-score, a 22% improvement in the T-score and a 14% improvement in the ST-score.

Finally, the riders rated the change from their standard stirrups to the Winderen Knee Protect Solution stirrups as having a mean value of 3.6 ± 1.2 where 1 represents no noticeable difference and 5 represents the most considerable difference they could imagine.

Discussion:

This trial project set out to test the hypotheses that; 1) Winderen Knee Protect Solution stirrups reduce the amplitude of the AMG signal around the knee joint of riders at low speeds and low levels of riding activity compared with standard iron stirrups, and 2) At high levels of riding activity the Winderen Knee Protect Solution stirrups reduce the time duration of loading forces around the knee joint of riders when compared with standard iron stirrups.

The data have shown a statistically significant difference between AMG parameters (E-, T- and ST-scores) at low speeds (walk), which is in agreement with the first and second hypotheses. However, due to the small sample size and lack of data power with this trial project, the changes found at higher speeds, whilst supportive of the first and second hypotheses, were not found to be statistically different. Power analysis shows with the current means and variance that a sample size of 34+ would be needed to achieve statistical significance for AMG parameters at trot and canter.

This trial project has found that the E-score improves when a Winderen Knee Protect Solution stirrup is used compared with a standard iron stirrup. Such an improvement signifies that for any given period of activity, less time is spent under stress or strain, both for the ligament as well as the muscle. In terms of the muscle, a Winderen Knee Protect Solution stirrup resulted in a reduction of stress or strain time in the order of 14 seconds per minute of activity whilst walking and some 5-7 seconds less whilst trotting or cantering. For the ligament, a Winderen Knee Protect Solution stirrup resulted in a reduction of stress or strain time in the order of 25 seconds per minute of activity whilst walking and some 9-10 seconds less whilst trotting or cantering.

It was likewise clear from the data that the force level in the muscle and ligament was greatly reduced when riding with a Winderen Knee Protect Solution stirrup compared to a standard iron stirrup. This was assessed using the mean of the AMG S-spatial summation and T-temporal summation parameters, which have been found to be very closely correlated with force (Claudel et al., 2018). A higher ST-score is indicative of fewer active motor units (muscle fibers) and a lower firing rate, which simply means the muscle needs fewer fibers to perform its activity, and in all cases an improvement in the ST-score with the Winderen Knee Protect Solution stirrups was noted; 22% at the walk, 17% at the trot and 26% at the canter. For the patellar ligament, similar improvements in the ST-score were noted; 20% at the walk, 14% at the trot and 14% at the canter. In summary, when using the Winderen Knee Protect Solution stirrups, the muscle and ligament experience lower forces exerted on them as a result of riding at different gaits.

The improvements in the ST-score and consequently the reduction in forces around the knee, are mostly seen through an improvement in the T-score, the firing frequency. In muscle this can be explained as a reduction in the need to tense up fibers and thereby stabilize a joint in response to a shock wave or ground reaction force traveling up through the limb from the stirrups. Thus, since Winderen Knee Protect Solution stirrups have been designed to reduce such shock wave or ground reaction forces whilst riding, this improvement in the T-score is not surprising. In the ligament we likewise measure the frequency of shock waves or ground reaction forces as they travel up through the leg. The improvement seen in the ST-score is therefore also to be anticipated, confirming that Winderen Knee Protect Solution stirrups do in fact reduce such shock waves or ground reaction forces around the knee whilst riding.

Our measurements did not reveal statistically significant differences in the AMG signal during trotting and cantering, however, the riders stated that they felt the greatest benefits of the Winderen Knee Protect Solution stirrups at these higher speeds (likewise those few who jumped), lending weight to our observations. A larger sample size would most likely show statistical significance for these higher speeds.

Conclusion:
It would appear from this trial project that Winderen Knee Protect Solution stirrups offer a number of advantages over standard iron stirrups. We have noted a reduction of stress or strain time in the muscle and ligaments around the knee during walking, trotting and cantering. These findings are supported by significant improvements in the AMG E-score and ST-score. We have also observed a considerable improvement in rider comfort and feeling of leg stability, compared with the owners current stirrups, whilst riding with Winderen Knee Protect Solution stirrups. Combined, these findings support the manufacturers claims that these stirrups do indeed offer a means of protecting riders knees from unnecessary forces and strains whilst riding.

Acknowledgements:
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Conflict of interest:
The authors are not retained by Winderen, nor do they own shares in the company. One of the authors was, however, compensated for their time (MK- www.Equi-Physiq.com) and the company was compensated for the materials used in this trial project. The riders received a free gift from Winderen for participating. Dr Adrian Harrison is establishing a company (CURO-Diagnostics ApS) to develop and produce the AMG equipment.

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