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The Use of Far Infrared Treatment Prior to Exercise in Horses: An mfBIA and Acoustic Myography Three Case Study

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Abstract

Background: Acute effects of Far Infrared (FIR) treatment in horses are unknown, especially short periods of 30 minutes, as is any effect on such muscle parameters as warm-up balance, overall exercise balance and laterality asymmetries. **Aim:** This study examines three equine cases in detail to measure any effects of a short period of FIR treatment. **Methods:** Multi-frequency bioimpedance (mfBIA) and acoustic myography (AMG), non-invasive techniques, were applied pre- and post-treatment with FIR to the back (T5-L4/5) and for m.Longissimus dorsi and m.Gluteus medius was recorded during a 15-minute warm-up regimen. mfBIA parameters included extracellular resistance (Re), centre frequency (fc), membrane capacitance (Mc), intracellular resistance (Ri) and phase angle (PA) which indicates level of training and health status. **Results:** FIR treatment responses for mfBIA parameters were found to be horse-specific and different, whilst in terms of AMG, FIR treatment for 30 minutes had a beneficial effect on overall balance in all three horses (5 out of 6 muscles), and a beneficial effect on the AMG parameter ST (force symmetry) in all three horses (6 out of 6 muscles). An overall improvement for combined balance and ST values for both muscles and all three horses of 86% was noted with FIR treatment, compared to 56% without. **Conclusions:** This preliminary study of FIR treatment in three horses, has been found to result in an overall improvement in combined balance and ST values for both muscles. FIR has potential as a promising treatment to reduce the risk of warm-up-related injuries in athletic horses.

Keywords

Equine, FIR, Muscle Balance, Muscle Force, Injury Prevention

1. Introduction

Applied heat is a well-known means of addressing musculoskeletal injuries [1]. Indeed, the physical work of exercise itself results in heat production, and applied heat has been reported to induce changes in the dynamics of connective tissue and muscle tissue, facilitating movement, increasing the range of motion and improving contractility [2] [3]. The question remains, however, as to whether other means of warm-up, such as FIR treatment could be used to optimize connective tissue and muscle layer function prior to an exercise regimen. Indeed, could FIR be an efficient and responsible way of reducing static-state and warm-up phase imbalance, facilitating responsible training and providing a means of safer pre-training warm-up? Research suggests that heat activates specific molecular structures affecting gene expression, anti-inflammatory and antioxidant pathways, biogenesis of mitochondria, heat shock proteins and muscle hypertrophy [1]. More specifically, microwave diathermy in human subjects has been reported to result in greater maximal voluntary contraction and improved range of motion following eccentric exercise [4] as well as reduced muscle soreness and increased recovery of maximal voluntary contraction [5].

At rest or in a static-state, joints are stabilized by the connective tissue and ligaments that surround them in conjunction with overlying muscle [6]. In this state, the connective tissue remains relatively stiff and supports the joints, but when a subject begins to exercise and the heat of physical activity (dynamic state) warms up connective tissue [7] [8], including fascia layers, the support afforded by connective tissue around joints is replaced by that of muscle tissue. Moreover, muscle improves in terms of force production when it is warmed up [9], and with the relaxation of connective tissue comes a greater range of motion [10].

The warming effect subjects feel with infrared rays comes from the far infrared (FIR) radiation (5.6 to 1000 μm) band. Whilst the range of their warming effects is known, the mechanism by which FIR radiation exerts its effect is not [11]. It is generally acknowledged though that FIR radiation penetrates through the skin and into underlying tissue (approx. 4 cm) [12] to reach and affect muscles, blood vessels, lymphatic glands and nerves in contrast with warm air [13]. To date, FIR therapy has been associated with an accelerated recovery to maximal strength, to alleviate discomfort and pain [13] [14] an example of which is the use of infrared radiation for chronic lower back pain [15]. FIR has also been reported to reduce vascular endothelial inflammation, and even to improve heart and coronary disease, as well as improve the variability of heart rate in subjects and subsequent fluctuations in systolic blood pressure [13]. In another study, it was found that a period of 3 weeks of FIR treatment in a sauna improved exercise tolerance and peak VO_2 as well as ventilation efficiency in exercise tests with chronic heart failure subjects [16].

Nearly all subjects seem to have a dominant side, one that they prefer to use when initiating movement or a change in gait, and very often it is the strongest

side of the body. When transitioning from a static state to one post-warm-up, it is not uncommon to be able to measure an imbalance between the dominant and non-dominant side of a subject, at least in terms of muscle activity [17]. Using the new analytical tool of acoustic myography it was recently shown that muscular imbalance in equine hind limbs could be detected, confirming the work of Clayton and colleagues [cited in 18]. The authors concluded, that not only could functional musculoskeletal asymmetry be measured during periods of activity using acoustic myography, but that a program of proprioceptive training could be used successfully to improve this muscular imbalance [18].

During the warm-up transition phase of physical exercise there is always the potential risk of injury [19] [20] [21], particularly if a subject has a noticeable imbalance and the subject is either eager or encouraged to overperform.

Whilst effects of FIR, such as they are, have not been documented in horses, devices that appear to work like a solarium, exist and are widely used in the equine world. The purpose of the present study was, therefore, to examine the effect of a 30-minute period of FIR treatment on a routine warm-up regimen in professional jumping horses, ridden by experienced riders. Three horses were examined as individual cases to measure changes in mfBIA parameters, assessing muscle status whilst the horses were in a static-state, and AMG parameters measured during physical activity. The hypotheses tested were that; 1) a short period of FIR treatment to the back of horses results in a noticeable improvement in the circulation in that region, as measured by a change in Re, as well as muscle tension (fc), and 2) that FIR treatment pre-warm-up has a measurable effect on the warm-up period, hastening an improvement in balance and muscle force.

2. Methods

2.1. Animals

The measurements presented in this manuscript were carried out in accordance with the Helsinki Declaration. The owner of the horses used gave their informed consent prior to the start of this study. In addition, this study was entirely non-invasive in its nature, and full ethical approval was gained from Copenhagen University Department of Pathobiological Sciences, Faculty of Health & Medical Sciences (protocol ID 2018-15-0201-01462; measurement dates 29 - 30th November 2023). The inclusion criteria were that horses were educated riding horses, accustomed to both bridles and a bit, that they were healthy and free from obvious pain or lameness.

Case 1: A 7-year-old gelding weighing 573 kg, trained to an international level (1.45), and reported by the riders to be slightly uneven on the right and left sides.

Case 2: A 4-year-old gelding weighing 595 kg, trained to the national level (1.00), and reported by the riders to pull a bit in the front, to have difficulty bending around the right leg but soft enough in the mouth, with a tendency to stable cramps in the right hind leg.

Case 3: A 5-year-old mare weighing 573 kg, trained to the youngster international level (1.25), and reported by the riders as having a very straight back as well as talking a lot.

2.2. Multi-Frequency Bioimpedance (mfBIA)

Horses were restrained calmly in a standing position whilst being kept free of all metal surfaces and human contact. Precisely determined anatomical areas were then prepared with the application of conductive paste (Ten20; Weaver and Company, Aurora, Colorado 80011 USA), which was rubbed in to make clean contact with the skin and avoid the inclusion of hair. Four custom-made pure platinum electrodes (10 mm × 25 mm; AH[1]*, DK) were placed on the prepared sites. A mf-BIA unit (ImpediVET BIS 1, Pinkenba, AU) providing 800 µA of current was subsequently attached to the platinum electrodes according to the manufacturer's recommendations, and recordings were carried out. The measurements were taken from the back of each horse defined as the region between m.Trapezius (caudal region; T5) to the m.Longissimus /m.Gluteus transition (L4-5).

Measurements were taken over a range of 256 frequencies (4 kHz to 1000 kHz) and repeated six times with a 1-second interval. Using this approach, any slight movement artifacts or changes in the resistance and reactance values due to cable movement, change in stance, body, or electrode movement were avoided. For details concerning the mf-BIA recordings see [22] [23].

The mf-BIA recordings were analyzed using the ImpediVET software. Cole-Cole plots were assessed at the time of recording to check for a normal distribution, and both the R and Xc plots were examined to ensure a precise measurement. Subsequently, a detailed analysis of each measurement was made for each horse using the 50 kHz data set. These subsequent analyses included the standard parameters of Z, R and Xc, as well as the phase angle (PA; arctan Xc/R), the fc, Re, Mc, and Ri parameters.

2.3. Acoustic MyoGraphy (AMG)

Acoustic myography (AMG) is a biomechanical method capable of recording pressure waves generated in the equine tissue, sometimes used in connection with equine equipment (stirrups, bridles, photobiomodulation, etc) [24] [25] [26]. AMG recordings were carried out using a CURO unit and sensors (CURO-Diagnostics ApS, Denmark) and followed in real-time on a smart device (tablet/phone) *via* a dedicated App "CURO Equine". A sampling rate of 1 kHz was used and recorded data were stored to the CURO App until completion of measurements, after which they were transferred to the CURO cloud (https://app.myodynamik.com) for analysis. Using this setup, it was possible to not only see the actual recordings while the horses were physically active but also to analyze the recorded data in minute detail in terms of balance (left *vs* right side) and the force produced (ST value), which has been shown to correlate

closely with maximal voluntary force [27].

2.4. AMG Balance

The AMG balance is based on a perfectly symmetrical overall E- S- and T-score for the left and right sides of the horse at the point of measurement (m.Trapezius - caudal region; T5) and the m.Longissimus /m.Gluteus transition (L4-5)). In such a case the E, S and T-scores would equal each other and result in a 0 score (e.g Left E = 6.5 S = 7.3 T = 8.1 minus Right E = 8.1 S = 7.3 T = 6.5 would give Left 21.9 – Right 21.9 = 0). For the purposes of this study, values within ± 3 of 0 were considered acceptable (see **Figure 1**) and values outside this range were deemed to be imbalanced.

2.5. AMG ST Parameter

The AMG ST parameter is a very good representative of muscle force and is calculated as the mean of the S- and T-scores for the left and right sides of the horse at the point of measurement. The final ST value is calculated as the ratio between the left and right sides, hence a value of 1.0 represents an even degree of force production at the point of measurement – values above or below 1.0 being indicative of more or less force production on one side of the horse (see **Figure 2**) (e.g. Left ST = 8.1 divided by Right ST = 6.5 would give an ST ratio of 8.1/6.5 = 1.2 – where the right side is working more).

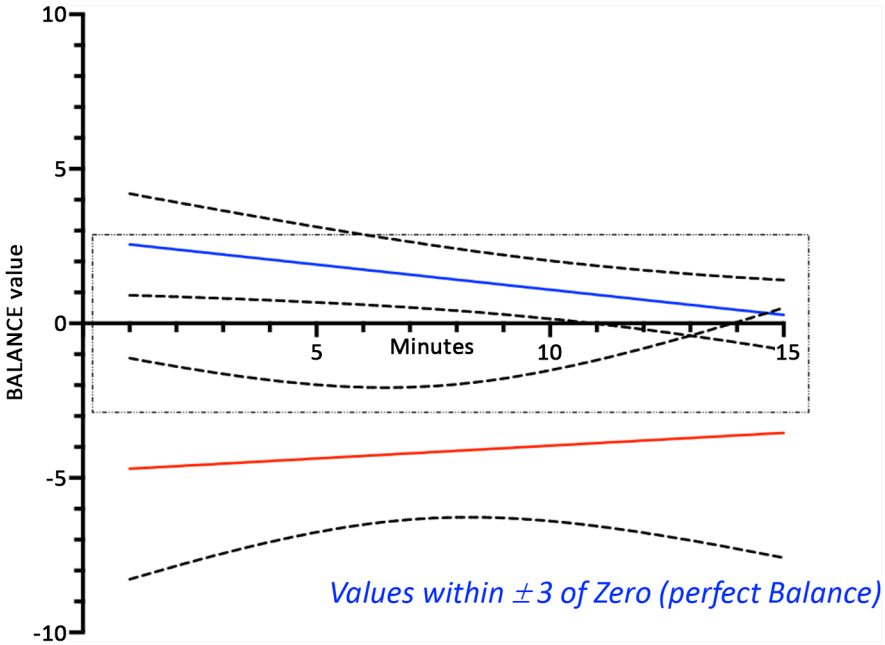

Figure 1. An example of a typical AMG balance assessment. The dotted box represents the region within ± 3 of the perfect balance value 0. The solid blue line with its confidence interval lines (dotted) is within the acceptable range throughout the period of warm-up. However, the solid red line with its dotted line confidence intervals illustrates a measurement where the AMG balance was considered unacceptable from the start and remained so throughout the warm-up period.

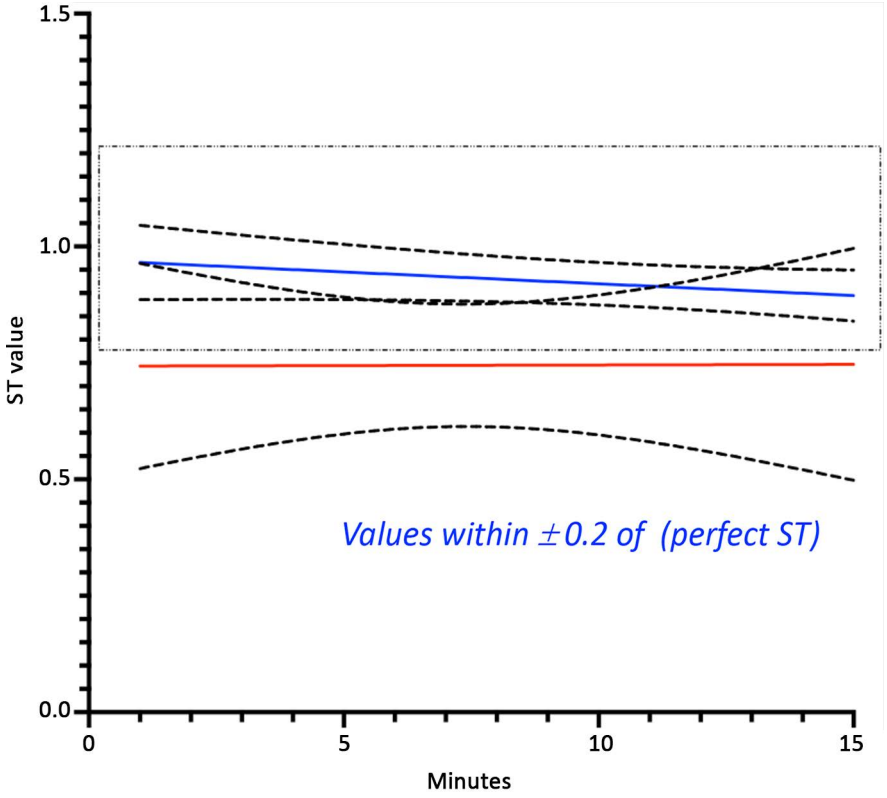

Figure 2. An example of a typical AMG ST assessment. The dotted box represents the region within ± 0.2 of the perfect ST (force) value which is 1.0. The solid blue line with its confidence interval lines (dotted) is within the acceptable range throughout the period of warm-up. However, the solid red line with its dotted line confidence intervals illustrates a measurement where the AMG balance was considered unacceptable from the start and remained so throughout the warm-up period.

2.6. Solarium and Thermal Imaging

A FIR Therapy Solarium manufactured in Sweden was used for this study (Stallvärme Sverige AB, Hagbyvägen, Åkersberga, Sweden), this system not only uses far infrared radiation (a form of electromagnetic radiation) that has a longer wavelength than visible light yet shorter than that of microwaves, it is also adjustable in terms of the panels placed around the subject and the duration of treatment. FIR is classified as being a part of the spectrum of radiant heat and has been documented to penetrate deeper into tissues and cells, and has been associated with therapeutic benefits to the body, such as wound healing [28]. The use of a FLIR One camera and the FLIR thermal studio (version 6.1.0; Wilsonville, Oregon, USA) was made to measure the thermal image of the horse´s back as well as the FIR Stallvärme solarium panels (see Figures 3-4). Measurements were made prior to the study to assess the FIR Stallvärme solarium panels, their uniformity and operating range, then again on the days of measurement, when there was a considerable snowfall (approx. 15 cm) and the daily temperatures ranged from −8.3˚C to −1.7˚C and −6.7˚C to −1.2˚C for the two days of measurement, respectively.

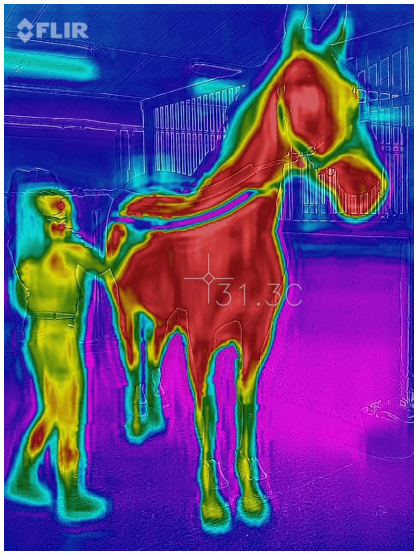

Figure 3. A typical FLIR thermal image of a horse and rider, showing body temperature as a colour scale where yellow-orange and red regions are warmer than green-blue and purple regions.

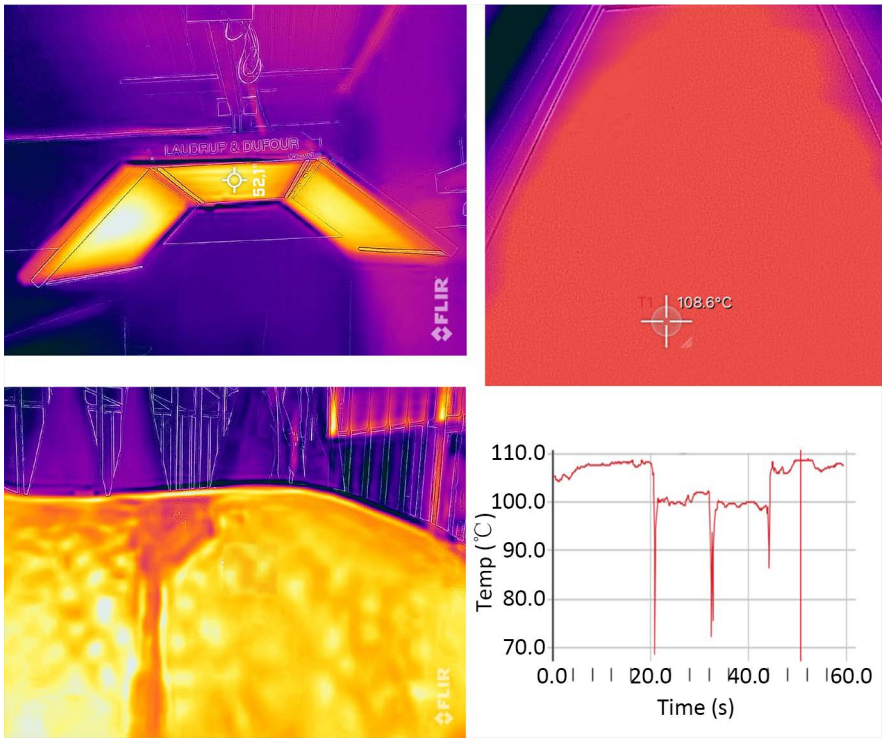

Figure 4. A composite FLIR thermal image. Top Left: FIR Therapy Solarium panels – Stallvärme AB, Top Right: A close-up of one of the panels showing a spot temperature of 108˚C, Bottom Left: A horse back whilst in a FIR Therapy Solarium unit (typically 108˚C), and Bottom Right: A typical multiple site reading for a FIR Therapy Solarium panel, showing the range of recording (100˚C - 109˚C) in this case.

2.7. Experimental Plan

Each horse was measured over two days, on the first day subjects were measured

using AMG for muscle activity without any FIR Therapy Solarium treatment (Stallvärme Sverige AB; Setting 1 for 30 minutes), and on the second day they were treated for 30 minutes in the FIR Therapy Solarium, after which mfBIA recordings were made for the back of each horse prior to attachment of AMG Curo sensors and units for muscle activity measurements during a normal training regimen.

2.8. Data Assessment and Statistics

The bioimpedance data were analyzed using the ImpediMed Inc software (Impedimed, Pinkenba, Qld, AU). Initially, the Cole-Cole plot was analyzed to assess its normal distribution, and subsequently, both the R and Xc plots were examined to ensure that a correct recording had been obtained. Following this, the Center Frequency (fc) and the Extracellular Resistance (Re) were determined from the Cole-Cole plot, and intracellular Ri was calculated from the formula: $Ri = (Re \times R\infty/Re - R\infty)$. Membrane Capacitance (Mc) was also calculated using the formula: $fc = 1/(2\pi \times Mc \times (Re + Ri)$. Finally, in accordance with other studies [22] [23], and to be able to compare individuals of different body mass, the Phase Angle (PA) was calculated: $PA = \arctan(Xc/R)$ with units in degrees. The mfBIA parameters were interpreted in terms of hydration status (Re), tissue density/resting tension (fc), membrane activity/integrity (Mc) and metabolic activity (Ri) [22] [23].

The AMG data were analyzed using the CURO recording system software, which is freely available (https://www.curo-diagnostics.com/), the details of which have been published [18] [25] [26]. AMG means of the first and second minutes of the warm-up training regimen were made, thereafter every second minute was averaged until the end of the training period (typically 15 minutes). Values in figures and tables are presented as the mean or as the mean ± the standard deviation of the mean.

3. Results

3.1. Thermal Imaging

An example of the FLIR One thermal imaging made during this study can be seen in the figure below (see **Figure 4**). Note the heat image for the FIR Therapy Solarium unit, and the three panels that can be lowered as well as angled in towards the horse. The temperature produced by the panels was measured to be between 100˚C and 110˚C. The skin temperature measured over the region of the back for the horses at rest was found to be 31.6˚C ± 0.2˚C (range 31.2 - 31.9), compared to after a 30-minute period of FIR Therapy Solarium unit treatment when it was found to be 32.5˚C ± 0.3˚C (range 32.0 - 33.1) – a mean increase of 0.9˚C.

3.2. mfBIA Parameters for the Three Cases

The mfBIA values for the three Cases presented in this preliminary study can be

found in Table 1 below. Note that the values are for the delta of the two measurements (without FIR Therapy Solarium unit treatment compared to with) and that a positive value indicates an increase between the two measurements, whilst a negative value indicates a decrease.

3.3. AMG Balance Values for the three Cases

The AMG balance results for the three cases measured in this study are shown below (see Figures 5-7).

Case 1*:* Found that for m.Longissimus dorsi and m.Gluteus medius the FIR Therapy Solarium treatment resulted in balance values that were entirely within ± 3 of the perfect balance value 0 from the start of the warm-up period and throughout the subsequent 15-minute long training regimen. In contrast, the same 15-minute period of warm-up exercise without FIR Therapy Solarium treatment resulted in a noticeable imbalance in both muscles, that improved over time but remained largely beyond the range of ± 3 of the perfect balance value. It should be noted that for both muscles, values within the accepted range

Table 1. mfBIA delta values (difference between measurements made on Day 1 (without FIR Therapy Solarium treatment) and Day 2 (with FIR Therapy Solarium treatment)) for the back region (T5 - L4-5). mfBIA parameters presented are for Re, fc, Mc, Ri and the PA. Mean values with range [..]. Reference values taken from well-trained hobby horses [22].

	Case 1	Case 2	Case 3	Reference Values
Re (delta value)	20.9 [93.5 to 72.6]	7.1 [88.6 to 81.5]	−4.9 [106.5 to 111.4]	[68.2 ± 3.6]
fc (delta value)	14.1 [52.7 to 38.6]	−5.0 [33.4 to 38.4]	−1.4 [32.0 to 33.4]	[37.1 ± 0.9]
Mc (delta value)	−20.3 [17.6 to 37.9]	2.4 [36.8 to 34.4]	4.8 [30.3 to 25.5]	[38.0 ± 3.2]
Ri (delta value)	42.3 [78.4 to 36.1]	1.8 [40.8 to 39.0]	−18.2 [57.3 to 75.5]	[48.5 ± 4.1]
PA (delta value) and [exact values]	3.0 [15.6 to 18.6]	0.5 [19.5 to 20.0]	−2.8 [19.1 to 16.3]	[15.6 ± 0.8]

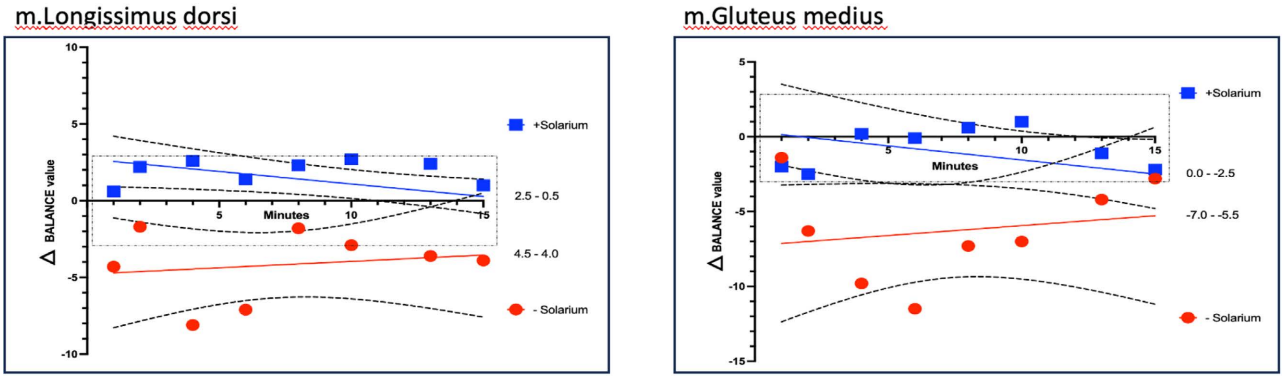

Figure 5. AMG balance assessment for Case 1 for m.Longissimus dorsi (left) and m.Gluteus medius (right). The dotted box represents the region within ± 3 of the perfect balance value 0. The blue squares and the solid blue line with its confidence interval lines (dotted) represents values for the AMG balance with FIR Therapy Solarium treatment. The red circles and the solid red line with its confidence interval lines (dotted) represent values for the AMG balance without FIR Therapy Solarium treatment. The range (start and end values) for the with and without FIR Therapy Solarium treatment values are given alongside the graph. AMG means of the first and second minutes of the warm-up training regimen were made, thereafter every second minute was averaged until the end of the training period (typically 15 minutes). Note that the scale for the delta balance values may differ between muscles.

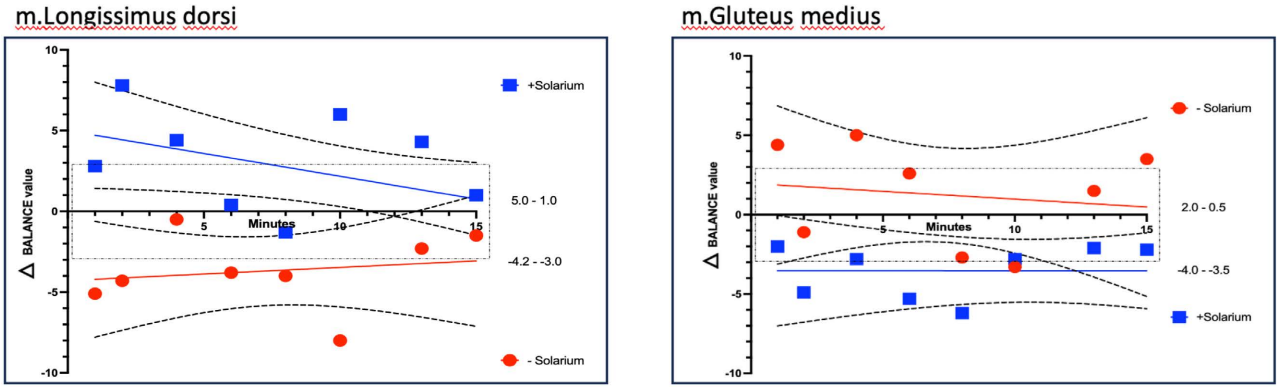

Figure 6. AMG balance assessment for Case 2 for m.Longissimus dorsi (left) and m.Gluteus medius (right). The dotted box represents the region within ± 3 of the perfect balance value 0. The blue squares and the solid blue line with its confidence interval lines (dotted) represents values for the AMG balance with FIR Therapy Solarium treatment. The red circles and the solid red line with its confidence interval lines (dotted) represents values for the AMG balance without FIR Therapy Solarium treatment. The range (start and end values) for the with and without FIR Therapy Solarium treatment values are given alongside the graph. AMG means of the first and second minutes of the warm-up training regimen were made, thereafter every second minute was averaged until the end of the training period (typically 15 minutes). Note that the scale for the delta balance values may differ between muscles.

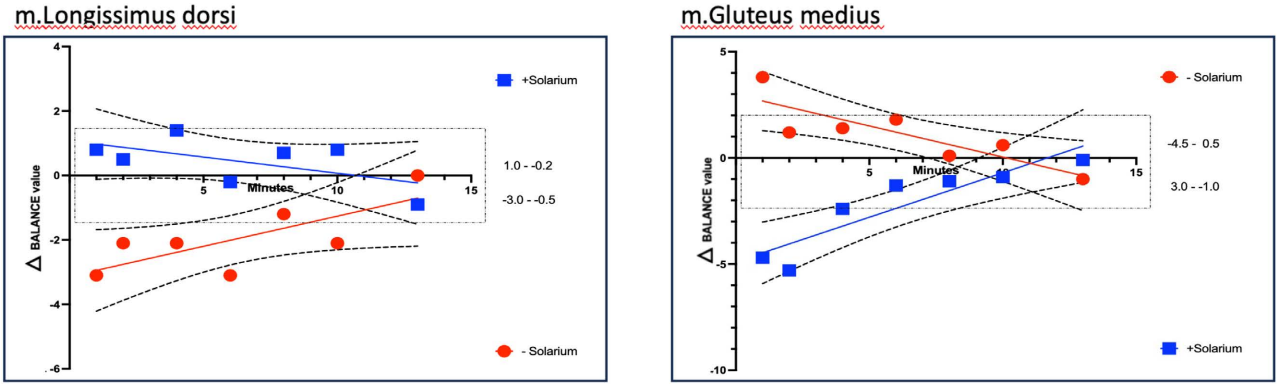

Figure 7. AMG balance assessment for Case 3 for m.Longissimus dorsi (left) and m.Gluteus medius (right). The dotted box represents the region within ± 3 of the perfect balance value 0. The blue squares and the solid blue line with its confidence interval lines (dotted) represent values for the AMG balance with FIR Therapy Solarium treatment. The red circles and the solid red line with its confidence interval lines (dotted) represent values for the AMG balance without FIR Therapy Solarium treatment. The range (start and end values) for the with and without FIR Therapy Solarium treatment values are given alongside the graph. AMG means of the first and second minutes of the warm-up training regimen were made, thereafter every second minute was averaged until the end of the training period (typically 15 minutes). Note that the scale for the delta balance values may differ between muscles.

of the perfect balance were 100% after FIR Therapy Solarium treatment, whilst values within the accepted range for these two muscles without FIR Therapy Solarium treatment were only 38% and 25%, respectively.

Case 2: Found that for m.Longissimus dorsi and m.Gluteus medius the FIR Therapy Solarium treatment resulted in balance values that were not entirely within ± 3 of the perfect balance value 0 from the start of the warm-up period. However, whilst both muscles showed a positive effect of the 15-minute long warm-up training regimen, only 50% and 62% of the values were found to be within the accepted range of the perfect balance after FIR Therapy Solarium

treatment, for m.Longissimus dorsi and m.Gluteus medius, respectively. In contrast, only 37% and 50% of the values were within the accepted range for these two muscles without FIR Therapy Solarium treatment, respectively.

Case 3*:* Found that for m.Longissimus dorsi balance values with FIR Therapy Solarium treatment were entirely within ± 3 of the perfect balance value 0 from the start of the warm-up period and throughout the subsequent 15-minute long training regimen (100%). However, without FIR Therapy Solarium treatment only 71% of the recorded values were within ± 3 of the perfect balance value. In contrast, m.Gluteus medius showed an initial imbalance both with and without FIR Therapy Solarium treatment, although values quickly adjusted to within ± 3 of the perfect balance value 0 as quickly as 2 - 4 minutes into the warm-up training regimen - 71% and 86% of the values were within the accepted range for m.Gluteus medius with and without FIR Therapy Solarium treatment, respectively.

3.4. AMG ST Values for the Three Cases

The ST values for the three cases measured in this study are shown below (see Figures 8-10).

Case 1: Found that for m.Longissimus dorsi and m.Gluteus medius the FIR Therapy Solarium treatment resulted in ST values (force) that were entirely (100%) within ± 0.2 of the perfect ST (force) value, which is 1.0, from the start of the warm-up period and throughout the subsequent 15-minute long training regimen. In contrast, the same 15-minute period of warm-up exercise without FIR Therapy Solarium treatment resulted in a noticeable imbalance in ST for m.Gluteus medius, and values of 75% and 38% within the accepted range for these two muscles without FIR Therapy Solarium treatment, respectively.

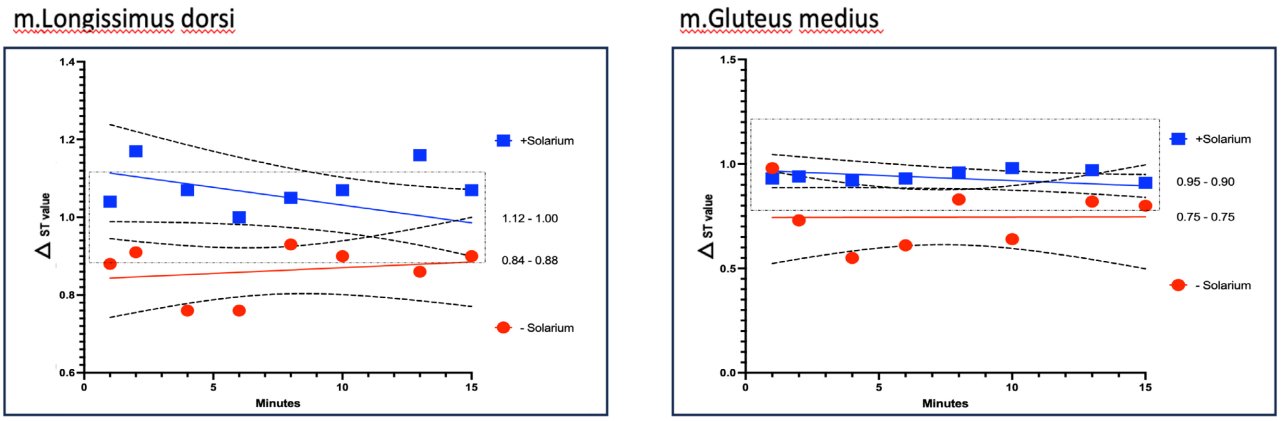

Figure 8. AMG ST assessment for Case 1 for m.Longissimus dorsi (left) and m.Gluteus medius (right). The dotted box represents the region within ± 0.2 of the perfect balance value 1.0. The blue squares and the solid blue line with its confidence interval lines (dotted) represent values for the AMG ST with FIR Therapy Solarium treatment. The red circles and the solid red line with its confidence interval lines (dotted) represent values for the AMG ST without FIR Therapy Solarium treatment. The range (start and end values) for the with and without FIR Therapy Solarium treatment values are given alongside the graph. AMG means of the first and second minutes of the warm-up training regimen were made, thereafter every second minute was averaged until the end of the training period (typically 15 minutes).

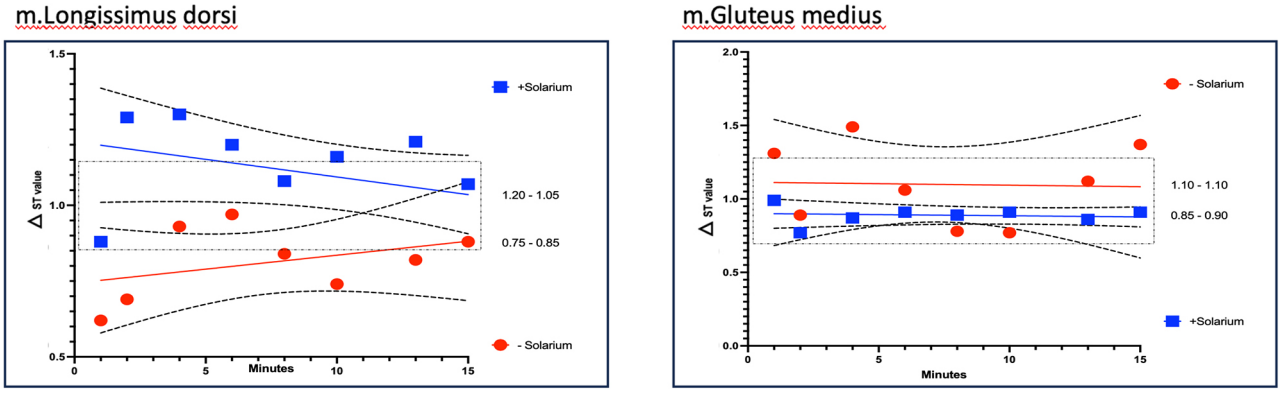

Figure 9. AMG ST assessment for Case 2 for m.Longissimus dorsi (left) and m.Gluteus medius (right). The dotted box represents the region within ± 0.2 of the perfect balance value 1.0. The blue squares and the solid blue line with its confidence interval lines (dotted) represent values for the AMG ST with FIR Therapy Solarium treatment. The red circles and the solid red line with its confidence interval lines (dotted) represent values for the AMG ST without FIR Therapy Solarium treatment. The range (start and end values) for the with and without FIR Therapy Solarium treatment values are given alongside the graph. AMG means of the first and second minutes of the warm-up training regimen were made, thereafter every second minute was averaged until the end of the training period (typically 15 minutes).

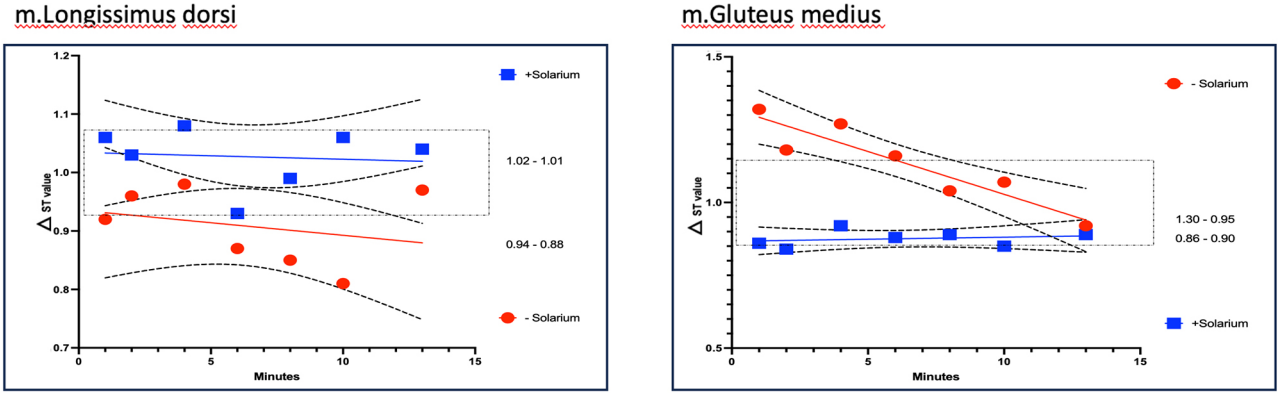

Figure 10. AMG ST assessment for Case 3 for m.Longissimus dorsi (left) and m.Gluteus medius (right). The dotted box represents the region within ± 0.2 of the perfect balance value 1.0. The blue squares and the solid blue line with its confidence interval lines (dotted) represent values for the AMG ST with FIR Therapy Solarium treatment. The red circles and the solid red line with its confidence interval lines (dotted) represent values for the AMG ST without FIR Therapy Solarium treatment. The range (start and end values) for the with and without FIR Therapy Solarium treatment values are given alongside the graph. AMG means of the first and second minutes of the warm-up training regimen were made, thereafter every second minute was averaged until the end of the training period (typically 15 minutes).

Case 2: Found that for m.Longissimus dorsi and m.Gluteus medius the FIR Therapy Solarium treatment resulted in ST values (muscle force) that were largely within ± 0.2 of the perfect ST value, which is 1.0; 62% and 87% for these muscles, respectively. No improvement for m.Longissimus dorsi in the ST value was found with FIR Therapy Solarium treatment, as the without treatment value likewise showed 62% of the values to be within the accepted range. In contrast, the same 15-minute period of warm-up exercise without FIR Therapy Solarium treatment for m.Gluteus medius resulted in a noticeable imbalance in ST with only 37% of values within the accepted range.

Case 3: Found that for m.Longissimus dorsi and m.Gluteus medius the FIR

Therapy Solarium treatment resulted in ST values (force) that were entirely (100%) within ± 0.2 of the perfect ST (force) value, which is 1.0, from the start of the warm-up period and throughout the subsequent 15-minute long training regimen. In contrast, the same 15-minute period of warm-up exercise without FIR Therapy Solarium treatment resulted in a noticeable imbalance in ST for m.Gluteus medius, and values of 85% and 71% within the accepted range for these two muscles without FIR Therapy Solarium treatment, respectively.

4. Discussion

To the best of the authors knowledge, this is the first scientific study involving mfBIA and AMG to examine any benefits to be gained by an experienced horse and rider, from a pre-exercise period of FIR Therapy Solarium treatment on physical performance as measured during a standard warm-up training routine. In terms of the hypotheses, this case study has been able to document that a short period of FIR treatment applied to the back region of horses results in a measurable change in both mfBIA and AMG parameters, and that FIR treatment pre-warm-up has a measurable effect on the balance and muscle force (ST) during a warm-up regimen.

Limitations: Whilst this is a small study in terms of the number of horses measured, it does serve to awaken an interest in the potential that FIR may well have for reducing warm-up-related injuries. The animals presented in this study were very similar in many ways, they were all housed at the same location, fed a similar diet, exercised in the same facilities and handled by the same personnel (grooms, riders etc.). It should be noted though, that this study was undertaken during adverse wintry weather conditions and that the author was not blinded to the experimental plan, although the riders were. It should be taken into consideration, however, that the riders in this study knew all the horses well and were very experienced professionals. Despite the aforementioned, this remains a three-horse study and there is now a need for a more detailed study that looks at the effects of FIR on not only mfBIA parameters in older horses as well as young ones, as well as consequences for muscle balance and force during warm-up.

Thermal imaging: From the point of view of FIR and its thermal effects, this study found that skin temperature values recorded at 31.6˚C ± 0.2˚C at rest and 32.5˚C ± 0.3˚C post FIR Therapy Solarium (Stallvärme AB) unit treatment compare favourably with published values of 30.9˚C ± 1.6˚C and 32.9˚C ± 2.4˚C [29]. Likewise, a published increase in skin temperature as a result of exercise of 1.0˚C (highest temperature before exercise of 31.1˚C *cf* 32.1˚C after exercise; [29]) compares favourably with the value of 0.9˚C measured in the present study with FIR treatment. One might tentatively conclude, therefore, that despite only three subjects, the effects of FIR treatment appear comparable to the thermal benefits afforded by physical exercise, at least at the level of skin temperature.

However, whilst it has been documented that heat activates specific molecular structures affecting gene expression, anti-inflammatory and antioxidant path-

ways, biogenesis of mitochondria, heat shock protein synthesis and muscle hypertrophy [1], these all represent changes that would not be likely to have a positive effect on muscle function, and certainly not within a short time frame of 30 minutes. Yet this study of just three horses has shown mfBIA and AMG changes that appear to be the result of just 30 minutes of FIR Therapy Solarium treatment, suggesting that heat has other effects on muscle and muscle function. Indeed, applied heat is known to induce changes in the dynamics of connective tissue and muscle tissue, facilitating movement, increasing range of motion and improving contractility [2] [3], and it was important to ascertain to what extent applied heat might be inducing its effects through changes in structural elements such as muscle, connective and vessel tissue by way of changes in bioimpedance values. This is particularly relevant since the mechanism by which FIR radiation exerts its documented effects remains as yet unknown [11], despite the fact that it is capable of reaching and affecting muscle tissue, blood vessels, lymphatic glands and nerves, in contrast to the application of warm air [13].

mfBIA parameters: The data for mfBIA indicate for Case 1 that FIR Therapy Solarium treatment resulted in much better perfusion of the back tissue, as indicated by the lower Re value, a reduction in resting tension (lower fc), an improvement in the membrane capacitance as well as a lower level of cellular metabolism (return to normal range; [22]). Overall, these changes combined, this horse showed an increase in the phase angle of 3.0 commensurate with an overall improvement in the other mfBIA parameters. For Case 2, the mfBIA data reveal a better perfusion of tissue (lower Re) with FIR Therapy Solarium treatment, although minimal change in tension (slightly higher fc) was found to occur. Likewise, this horse showed minimal change in the membrane capacitance and cellular metabolism (Ri) values, both of which were in the normal range [22]. Overall, these changes combined, this horse showed a minimal change in the phase angle of 0.5 commensurate with very little improvement in the other mfBIA parameters. Finally, for Case 3, the mfBIA parameters showed a very different pattern from the other two horses, in that this horse exhibited a slight reduction in tissue perfusion (higher Re) with FIR Therapy Solarium treatment. There was minimal change in tension (fc), a slight decrease in membrane capacitance and an increase in cellular metabolism (above normal range; [22]. Overall, taken in combination, the mfBIA values for this horse show a decrease in the phase angle of 2.8 commensurate with the other mfBIA parameters.

The animals in this study differ also in other ways, for example in their age and experience, and quite possibly their temperament. The mfBIA values obtained from these three horses (Cases 1 - 3) also show that they differ one from another. The big change in extracellular resistance (Re) in the back region for Case 1 was much less for Case 2 and inverted for Case 3. Since FIR might be considered as a means of warming tissue, then it is interesting that a change in the Re parameter, which relates to the local hydration of tissue, with high values representing a relatively hypotonic state around cells [30] and low values asso-

ciated with injury and swollen tissue [31], did not show a common response. Instead, the FIR treatment resulted in an animal-specific change in this parameter. Other mfBIA parameters likewise showed an animal-specific response (fc, Mc and Ri), which could indicate that FIR has a beneficial effect on certain animals. Of interest is the measurement that the phase angle (PA) parameter, which indicates healthy/disease states in humans and other mammals, followed the Re changes and revealed a clear improvement for Case 1 and minor improvement for Case 2 and a slight decrease for Case 3. Low phase angle values are consistent with a low reactance and equate either to cell death or a breakdown in the selective permeability of the cell membrane. In this study, the FIR benefit to not only Re but also the PA parameter in Case 1 is most likely the result of improved perfusion to the back region with an increase in nutrient provision and oxygenation of the measured tissue. It should also be noted that FIR treatment in Case 1 also resulted in a lower fc parameter, which is indicative of muscle relaxation, something that would facilitate better perfusion. In Case 2 where no real muscle relaxation was observed, there was a clear if smaller improvement in perfusion with FIR treatment. However, in Case 3 no appreciable change in Re was noted, nor any real change in fc, in fact a lower Mc was noted with FIR treatment, and an elevated Ri. This finding for Case 3 could be explained by the restless nature of this subject during the FIR treatment, that as a young horse seemed eager to get going with training and did not relax in the same way the other two horses did during their 30-minute period of FIR Therapy Solarium treatment. A restless, eager nature could be expected to induce the release of systemic adrenaline, which has been shown to have an inhibitory effect on membrane capacitance in excitable cells [32] [33], going some way to explaining the decrease found for Mc in Case 3 and the elevated Ri value. Yet, whilst mfBIA results are revealing and interesting, they are always taken pre-exercise in a rested state and as such are only representative of the static- and not the dynamic-state of a subject.

It is known that microwave deep heat treatment "diathermy" in human subjects induces an increase in maximal voluntary contraction [4] as well as an increase in recovery of maximal voluntary contraction [5], findings that fit very well with the beneficial FIR Therapy Solarium treatment response observed in this study for the acoustic myography ST parameter that has been shown to correlate so well with voluntary force production [27].

AMG parameters: Whilst each of these three Cases has been assessed independently of one another, were one to examine the mean of the effects based solely on the percentage of values within the accepted ranges (Balance and ST) during the 15-minute period of warm-up, then Case 1 would present with 100% of values in range after FIR Therapy Solarium treatment compared to a value of 45% without FIR treatment. Likewise for Case 2 a finding of 65% of values were in range after FIR Therapy Solarium treatment, compared to a value of 46% without FIR treatment. Finally, for Case 3 a finding of 93% of values in range after FIR Therapy Solarium treatment was noted compared to a value of 78%

without FIR treatment. Taken as a whole, all three cases, both muscles and the two AMG parameters, then 86% of values were found to be within range after FIR Therapy Solarium treatment, compared to 56% without FIR treatment.

AMG has been shown to be a good tool for assessing the dynamic nature of muscles. It has been used on humans and animals alike over recent years [18] [34] [35] [36] and has revealed how muscles are used for different activities and gaits, displaying as it does the number of active fibres (spatial summation: S-score), their firing rate (temporal summation: T-score) and the level of coordination or efficiency with which they are used (E-score), all of which are used by the motor cortex to generate force in skeletal muscles. Indeed, the level of force generated by muscles is closely correlated with the mean of the S- and T-scores, the ST parameter [27]. The other parameter of use when assessing subjects that are physically active is the AMG balance score, the sum of the left-minus the right-side E- S- and T-scores.

The transition from a static-state to one post-warm-up, is often associated with a measurable improvement in balance between the dominant and non-dominant side of a subject, at least in terms of muscle activity [17]. It was interesting to note in the present study therefore, that the warm-up exercise period itself resulted in an improvement in overall balance as well as the ST difference besides the noticeable benefits provided by FIR treatment. In young human sports athletes, a period of warm-up exercise was recently found to improve acute balance control only in the dominant leg, and the effect was reported as being more characteristic of subjects with experience of asymmetric sports [17]. This interesting finding was confirmed by another research group that investigated the acute effects of a single warm-up session on inter-limb balance asymmetries in the symmetrical sport of cycling [37]. Postural control performance of the dominant and non-dominant legs of athletes was evaluated using a Biodex Balance System and the authors concluded that warm-up exercise only improved acute postural control in the dominant leg of subjects [37]. Whilst inter-limb asymmetries in balance control are characteristics of lateralization in the control of movement, it has been suggested that this asymmetry may originate from hemisphere specialization for the utilization of somatosensory cues [38] such that processing of somatosensory information and proprioception is better in the non-dominant limb than in the dominant limb [39].

In terms of body balance, there are a number of reasons why one side of a subject´s body may be stronger than the other (out of balance), genetics for one, but also through acquired habits, or life events that may subsequently contribute to muscle imbalance. In terms of genetics, cross-dominance (sometimes referred to as mixed laterality) refers to an individual´s preference to favour motor skills on one side of the body e.g. to start to climb stairs with the right leg first, mount a bicycle from the left, pick up a cup with the right hand, and animals exhibit similar traits of cross-dominance [40]. Indeed, horses are known to have at least two laterality preferences, one that affects the olfactory system and the other af-

fecting motor function [40]. Thoroughbred horses have been measured as not only preferring to use their right nostril when smelling something presented to them, but to do so up until they reach the age of 4 years, but not when they become older [40]. The same study also found that the majority of horses tend to stand with the left forelimb advanced over the right when out at pasture grazing, indicating motor laterality [40]. Indeed, McGreevy and Rogers concluded that lateralization of the equine brain appears to occur on at least two levels of neural organization, sensory and motor [40]. However, an alternate explanation for the motor function observation—*left forelimb advanced over the right*—may be found instead with the myofascial kinetic lines of horses, and in particular the spiral line [41]. However, the present findings from these three case studies serve to support the presence of a motor laterality difference in horses, whatever their cause, showing that for Case 1 in particular there was considerable overall imbalance and ST difference for m.Gluteus medius at least, when horses were exposed to a 15-minute warm-up period.

Whilst it is dangerous to draw too many conclusions from this preliminary FIR Therapy Solarium treatment study, it is interesting to note that although mfBIA and AMG changes were observed, they do not necessarily show any clear correlation. For example, what might be deemed as minimal to detrimental changes in mfBIA were found in Case 3, yet despite this FIR Therapy Solarium treatment improved the ST difference in m.Gluteus medius during warm-up and the overall AMG balance for m.Longissimus dorsi. Perhaps the FIR Therapy Solarium effects on mfBIA parameters of muscle are independent of the changes observed in the AMG parameters, and not just the result of improved perfusion or tissue relaxation? It is proposed that these findings should now be the focus of a larger study on the effects of FIR treatment in horses, perhaps with a view to reducing the time spent on pre-training "warm-up", and also improving balance and force production during training and competition. If confirmed by a larger cohort study, then the benefits of FIR Therapy Solarium treatment could ultimately reduce the risk of "warm-up" related injuries such as strain to muscle or sprain to ligaments and joint capsules, which are reported as being a potential risk of injury during the warm-up transition phase of physical exercise [19] [20] [21].

5. Conclusion

An effect of FIR Therapy Solarium treatment was found to speed up, and in certain cases improve, the benefits otherwise gained from a pre-training exercise period of "warm-up", improving not only the balance between muscles on the left- and right-hand sides of the horses, but also improving force production. This very limited study of only three cases suggests that FIR Therapy Solarium treatment might greatly benefit older and perhaps stiffer horses, although a much larger cohort study is now required to confirm these positive yet tentative findings.

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Institutional Review Board Statement

This research was non-invasive in nature and was assessed and approved for ethical compliance by the University Ethics Committee—protocol ID 2018-15-0201-01462.

Informed Consent Statement

Informed consent was obtained from the horse owner and stable manager involved in the study.

Data Availability Statement

The author is happy to share data and to collaborate with those who find this research of interest.

Conflicts of Interest

AH is in the process of establishing a company to produce and market the Acoustic MyoGraphy system (CURO-Diagnostics ApS) but has no vested interest in Stallvärme Sverige AB, nor has he received any financial gain.

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