Title:

Sixty seconds of foam rolling does not affect functional flexibility or change muscle temperature in adolescent athletes

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Abstract

Background: Foam rolling is commonly prescribed by physiotherapists and practitioners but the mechanistic effects of this intervention are not known.

Purpose: The aim of this investigation was to establish if a single bout of foam rolling affects flexibility, skeletal muscle contractility and reflected temperature.

Methods: Twelve adolescent male squash players were evaluated on two separate occasions (treatment and control visits) and were tested on both legs for flexibility of the hip flexors and quadriceps, muscle contractility as measured by tensiomyography and temperature of the quadriceps assessed via thermography at repeated time points pre & post 60 s rolling intervention (pre, immediately post, 5, 10, 15 & 30 minutes post). They rolled one leg on the treatment visit and did not perform rolling on the control visit.

Results: The main outcome measure was the flexibility of hip flexor and quadriceps at repeated time points up to 30 minutes post intervention. The average foam rolling force was 68% of subject's body weight. This force affected the combination of hip and quadriceps flexibility ($p=0.03$; 2.4 degrees total increase with foam rolling) but not each muscle independently ($p = 0.05 – 0.98$) following a single 60s bout. Muscle contractility is not affected ($p = 0.09 – 0.93$) and temperature is not increased by foam rolling across time points ($p=0.19$).

Conclusions: A single sixty-second bout of rolling applied to the quadriceps induces a small significant change in flexibility that is of little practical relevance, while muscle contractility and temperature remain unchanged. Investigation of larger doses of rolling is merited in athletic populations to justify current practice.

Level of Evidence: 2c

Keywords: Adolescent; Flexibility; Tensiomyography; Thermography

INTRODUCTION

The use of self-myofascial release techniques to aid recovery[1,2] using a foam roller is increasingly popular,[3] particularly as it is one of the first steps used by a pro-active athlete in self-management of complaints.[4] The practice of foam rolling appears to have outpaced the scientific literature with limited publications available on its use.[3] Rolling is believed to have similar effects to massage, which include relief of muscle tension, increased flexibility, and improved range of motion (ROM).[5–7] There are claims that foam rolling can increase blood flow and joint ROM[3] although such claims are mostly inferred from research that has been performed on massage.[4] Currently there are no specific recommendations regarding the duration of foam rolling.[8] While studies have been performed, none have examined the dose response of differing bouts to investigate the relationship between frequency and or volume with outcome. All studies to date have used multiple bouts either within or across muscles without justification. Only one study to date has examined the pressure exerted on the foam roller during the activity[9] and a separate study has examined the force that is exerted through the roller.[10] The differing forces through the roller and subsequently muscle based on individual's technique and body mass may influence the outcome from foam rolling.

Several studies have shown that ROM is improved by foam rolling.[1,10–13] Each of these studies assess the effects of foam rolling after exercise. There have been no considerations of foam rolling from a starting point of no exercise in order to elucidate the mechanism for any action it may have. It has been proposed that thixotropy, in which heat or pressure is applied to a material in order to make it less dense and more fluid[4,14] may contribute to the effectiveness of foam rolling.

If thixotropy is an important mechanism of action, the ability to quantify a temperature change that an intervention induces would appear to be essential.[15] Foam rolling induced changes in ROM have been suggested to be associated with changes in temperature[16]. The use of a non-contact diagnostic tool such as thermography allows for quantification of any temperature changes[15] induced by foam rolling that have not previously been described.

Any temperature changes may in turn affect the muscle's contractile properties such as contraction time and force production.[17] Tensiomyography (TMG) can evaluate the involuntary contractility of the muscle and is influenced by the viscoelastic properties of the muscle. TMG has commonly been used to assess the muscle damage caused by an intervention[18] but has also been used to monitor muscle alterations that occur following bed rest[19] and to assess any effects of recovery strategies.[20,21] TMG as a technique measures the maximal radial displacement of the muscle belly via a digital transducer, when a contraction is generated by an external electrical stimulus. It offers information about different parameters relating to the magnitude and speed of muscle contraction and the mechanical properties of skeletal muscle.[22] TMG can non-invasively quantify muscle function through measurement of muscle stiffness, time and speed of contraction and any subsequent changes in these variables from an intervention.[23]

The goal of any foam rolling or myofascial release is to influence flexibility and/or ROM. Flexibility has been widely researched using a range of different methods and devices.[24–26] Some utilized active participants,[27] others passive.[28] Few have utilized a standardized force during application[29,30] in order to ensure that the measurement of flexibility is not simply a measure of a patient's tolerance to a stretch. This ensures reliable technique with an objective end point. Foam rolling is commonly prescribed by physiotherapists and applied strength and conditioning practitioners but the mechanistic effects of this intervention are not known. The aim of this investigation was to establish if a single bout of foam rolling affects flexibility, skeletal muscle contractility and reflected temperature. The hypothesis was that flexibility would increase due to foam rolling with concurrent reduction in contractility of the muscle and increases in temperature. The null hypothesis was that there would be no effect of foam rolling on the measures of flexibility, muscle contraction or muscle temperature.

METHODS

Subjects

A prospective cohort of male adolescent squash players from an elite sports school (n=12, 55.0±13.4 kg, 160.7±13.5 cm, 67.7±32.6 Σ8 skinfolds mm, -0.08±1.7 yrs from Peak Height Velocity, 14.2±1.4 yrs) were utilized. Testing was conducted on two separate occasions separated by 7-12 days. In each case testing took place following a standardized rest day. The treatment leg and order was determined by an online randomization tool (sealedenvelope.com), which was then matched to the 12 subjects by drawing from a hat. The study was approved by both the local research and University ethics committees and conformed to the recommendations of the Declaration of Helsinki.

Protocol

On one occasion (treatment) the subject performed the rolling intervention on the anterior part of the thigh of one leg while the contralateral limb acted as a control and on the other occasion (control) the subject lay in a prone position for the same duration but with no foam rolling to act as a full control. On both occasions the intervention occurred at the start of the athlete group's morning training session (1000 – 1200h) before any exercise had been undertaken and following a rest day. Athletes were free from injury, and were excluded from testing if they were not able to complete in all aspects of training.

Using the low and flat section of a commercially available foam roller (Figure 1A; The Grid, Trigger Point, Texas, USA) the subjects performed rolling on the thigh of the treated leg. They placed their body weight on the foam roller, which was placed on a force plate (400 Series Force Plate, Fitness Technology, Adelaide, Australia) sampling at 600 Hz. This measured the actual force applied through the roller throughout the intervention. Other than the leg on the roller (or force plate in the control condition) the subjects had two points of contact with the floor, both forearms placed in front of the force plate (Figure 1B). The non-rolling leg was elevated and fixed in a plank position via activation of posterior chain musculature. The rolling leg did not contact the floor. The body was held in a straight line with the trunk stable and the subject facing the floor. The subjects started at the proximal aspect of the thigh and rolled down toward the knee in one fluid motion. Upon reaching the required depth, the direction was reversed. The speed was controlled by a metronome (2s per pass) and the depth was visually indicated by tape on the force plate corresponding to the length of the subject's thigh. The rolling intervention covered the full anterior thigh musculature from just below the anterior-superior iliac spine to just superior to the patella. The duration of the rolling intervention was 60s reflecting the minimum dose prescribed by physiotherapy professionals working with the athletes, meaning that 30 full rolls were completed (15 in each direction).

*** FIGURE 1 NEAR HERE***

Prior to undertaking any foam rolling the subjects were asked to stand with their feet aligned to markers on the floor, to ensure a consistent position (feet shoulder width apart), in front of a rubber mat, to minimize reflected heat from the environment, for a thermal image to be taken to assess the baseline condition of reflected temperature. Subjects were then assessed for flexibility (passive ROM) of the quadriceps and hip flexors using the *'angle at force standardized endpoint'* technique.[30] Subjects then underwent Tensiomyography assessment (TMG) to examine the state of the muscle. These measures were repeated at 0, 5, 10, 15 and 30 minutes post intervention to examine any acute effects of the foam rolling intervention, subjects lay in a supine position between measures. The measures were taken from both left and right limbs to allow each subject to serve as their own internal control.

Procedures

Flexibility

The primary outcome measure was that of hip flexor and quadriceps flexibility. The method used to assess flexibility replicated the method described by Fourchet and colleagues of the *'angle at force standardized endpoint'*,[30] a video based method for flexibility assessment that has been established to have moderate-to-good reliability when used to monitor the passive ROM of adolescent athletes.[30] The same investigator consistently manipulated the patient and analyzed the video for the angle, to minimize test-retest variance. The camera obtaining the image was always perpendicular to the end of the plinth and at a distance of 3m with the same zoom setting. A hand-held dynamometer (Compact force gauge, Mecmesin, Slinfold, United Kingdom) with a digital scale (0.01-N increments) was used to apply the standardized force. The flexibility assessments were performed with the athlete supine. For the hip flexor measurement the pelvis was aligned at the end of the plinth. Following marking of identifiable anatomic landmarks with a dermatological pen for easy identification on the video, the operator maintained the non-tested limb in a maximally flexed position towards the abdomen, and allowed the lower limb to be tested to hang off the end of the plinth in neutral rotation. The tested limb was further extended with a force of 98.1N. The hip flexor measure was the angle formed between the body and the extended lower limb, as measured from a digital image.

For the quadriceps measure the patient's position was adjusted so the mid-thigh was now aligned with the end of the plinth. The uninvolved limb was maintained in a maximally flexed position towards the abdomen and the lower limb to be tested was in neutral position. The dynamometer was used to passively flex the tested knee with a force of 78.5N. The quadriceps measure was the knee flexion angle, as measured from a digital image. The measurements were then repeated on the contralateral side. Regardless of the treatment side the subjects left leg was assessed first at each time point.

Using the digital images obtained during the tests, digital motion analysis software (Dartfish, Classroom v.5.5, 2009, GEAR Software B.V., Helmond) was employed to measure the angles of interest. This occurred in a blinded fashion with the angles only matched to the trials after all analysis was complete. The final angles for each muscle group were measured to the nearest 0.1^{o} according to the marked anatomic landmarks. Overall flexibility of the leg was taken as the combined flexibility (sum) of the hip flexor and the quadriceps angles for each limb.

TMG

For a non-invasive measure of muscle contractility, Tensiomyography was employed. This technique creates radial displacement of the muscle belly in response to an electrical stimulus (~100mA) conducted through the underlying muscle tissue. These displacements are recorded at the surface of the skin using a spring loaded displacement sensor (TMG-BMC Ltd, Ljubljana, Slovenia). The sensor was consistently retracted to 50% of its length to ensure a consistent initial pressure. The sensor was positioned perpendicular to the thickest part of the rectus femoris muscle belly.[22] This position was established with visual inspection of the voluntary contracted rectus femoris and palpation of the area.[21] Self-adhesive electrodes were placed ~5cm on opposite sides of the sensor in the sagittal plane, over the rectus femoris. Once the exact position of the sensors was determined they were marked with a dermatological pen to ensure placement remained constant throughout the visit. Before proceeding an acetate layer was used to mark the sensor and electrode positions over the skin on each leg. This traced the placement as well as any anatomical or visual landmarks for each subject to ensure consistent placement on the second visit.

All measurements were performed with subjects in a supine position on a padded plinth. A triangular foam wedge was placed under the knee to create a knee joint fixed at 120^{o} angle.[21] A series of contractions of increasing amplitude (~10mA) was used to obtain a maximal response i.e. no further muscle displacement could be produced as evidenced by a plateau in the twitch response curves.[22] Only the maximal output data were used for analysis. Maximal radial muscle belly displacement (Dm), contraction time between 10 and 90% Dm (Tc) and the time taken from onset of the electrical stimulus to 10% of the maximal radial displacement (delay time; Td) of the rectus femoris were measured via TMG at each time point. These collective measures provide a comprehensive analysis of muscle state[31] with each representing a different facet of contractility. Dm (expressed in millimeters) depends on the muscle tone or stiffness. High scores indicate a lack of muscle tone (i.e. more compliant and relaxed muscle – expected after rolling). The time variables (measured in ms) represent the reaction time of the muscle (Td) and the subsequent time to contract (Tc). Associating the changes in Dm, Tc and Td can give insight into changes caused by foam rolling (i.e. a decrease in Dm with increase in Tc and Td would suggest fatigue[31]).

Thermal Imaging

Thermography is a non-invasive technique used to measure specific thermal responses at a superficial level.[32] The technique has previously been used to help quantify objective measures that have previously required subjective feedback such as the effects of massage.[33,34] Following palpation of the area for TMG placement a 50 x 50 mm area was marked around the area where the electrode was to be placed, this was marked by four strips (3 x 50 mm) of inert aluminum tape (3M, Minnesota, United States) to allow measurement of a consistent region of interest from the thermal images. In post processing a consistent marker was placed in the software to allow assessment of the majority of the quadriceps. From the sample this size was 110 x 46 pixels. This size was chosen as it covered the majority of the subject's anterior thigh without being too large (i.e. it exceeded the musculature and captured the background area within the area).

An infrared camera (FLIR T600, FLIR Systems, Oregon, USA) was positioned on a level tripod directly in front of the area where the subject was to be photographed at a distance of 2m. The height of the tripod was consistent across all subjects and allowed a clear image of the lower half of the body to be taken. The camera was allowed to stabilize in the environment 60 minutes before the first picture was taken.[35] A constant skin emissivity was set to 0.98 in accordance with previous research. [36] Prior to images being taken the camera was calibrated for the reflected heat and ambient conditions using the protocol recommended by the manufacturer. Images were taken pre the intervention, immediately post (0 minutes) and at all subsequent time points (5, 10, 15 and 30 minutes) with a consistent position of the subject and camera.

<u>Statistical Analysis</u>

Data are presented as mean ± SD. A 0.05 level of confidence was selected throughout the study. Statistical analyses were conducted using Minitab 17 (Minitab, Pennsylvania, United States). The normality of each measure was established. Each measure in turn was assessed as the independent variable against the time, condition and the interaction. A general linear model for repeated measures was used to assess normalized differences between conditions standardized to the Pre-condition and the force applied for each visit with factors of Time, Condition and their interaction for each variable. Post-hoc analysis was undertaken using Tukey's HSD. The difference between the treated leg and the control leg were normalized for each time point to the initial Pre-measurement for each variable in each condition. Then the difference between the treatment condition and control condition were calculated and assessed after interactions between time and group were also examined.

In addition, probabilistic magnitude-based inferences about the true value of outcomes were employed for variables with a practical relevance.[37] Dependent variables were analyzed to determine the effect of the designated intervention as the difference in change following each condition. To calculate the possibility of benefit, the smallest worthwhile effect for each dependent variable was the smallest standardized change in the mean – 0.2 times the between-subject SD for baseline values of all participants.[37] This method allows practical inferences to be drawn using the approach identified by Batterham and Hopkins.[37]

Inter- and intratrial reliability analyses were conducted on all dependent variables. All data used for reliability analyses were obtained from the control limb. Intertrial reliability was established using data obtained over the course of each individual trial. Intrasession reliability was established via analyzing data from the same time points across control and treatment trials. Reliability was determined using intra-class correlation coefficients (ICC), calculated using the two-way random method, Pearson's correlation coefficients (*r*) and coefficients of variation (CV) as previously described. [38]

RESULTS

Flexibility

While there were differences between subjects for flexibility of hip flexor (p=0.01) and overall flexibility of the leg (combined flexibility of hip flexor and quadriceps) (p=0.01), there was no effect on quadriceps (p=0.37). There was no effect on hip-flexor, quadriceps or overall flexibility over time (p=0.20, 0.74 & 0.34 respectively). For condition there was no difference on hip-flexor (p=0.62) or quadriceps (p=0.05) flexibility (individually) though there was for overall change in flexibility where the control condition was 2.4 degrees lower overall than the treatment (p=0.03). There were no significant interactions for hip-flexor, quadriceps or overall flexibility (p=0.21, 0.98 & 0.31). The individual values are plotted in Figure 2 along with the mean values. The raw mean values are shown by treatment and condition in Table 1.

Magnitude based inferences

There were differences practically at 15 and 30 minutes using the inferential approach. In terms of flexibility there was a small effect in overall flexibility of the hip flexor and quadriceps combined that was possibly trivial mechanistically at 15 minutes post. At 30 minutes this difference was no longer present. While there were small changes in the hip-flexor and quadriceps data at 15 minutes the practical conclusion is that there are not enough data to be certain of this effect.

*** TABLE 1 NEAR HERE ***

<u>TMG</u>

There was no effect on Tc, Dm or Td of time (p=0.99, 0.49 & 0.76 respectively), condition (p=0.10, 0.24 & 0.64), nor were there any time*condition interactions (p=0.52, 0.98 & 0.18). The individual values are plotted in Figure 2 along with the mean values. The raw mean values are shown by treatment and condition in Table 1.

Magnitude based inferences

There were some differences practically at 15 and 30 minutes using the inferential approach. In terms of Tc there was a moderate effect that is possibly negative at 15 minutes (i.e. the rolling condition increases the contraction time (slower activation)) at 15 minutes post. At 30 minutes this difference was small but positive rather than negative (i.e. the rolling condition demonstrated a decrease in the contraction time in comparison to the control). At 30 minutes there was a moderate increase in the delay time in the treatment condition that is likely negative (i.e. rolling causes the muscle to activate more slowly).

*** FIGURE 2 NEAR HERE***

<u>Thermography</u>

Small area (23 x 20 pixels)

As presented in Figure 3 it is evident that there were no differences in temperature across each time point (p=0.16). There were differences between conditions with the control condition being colder by 0.17^{o}C (p<0.01), although no time x condition interaction was present (p=0.59).

Large area (110 x 46 pixels)

When analyses were performed on the entire quadriceps region a condition interaction was observed ($p=0.001$) with the limb being colder in control condition (-0.15ºC), although no time x condition interaction was present ($p=0.08$). The raw mean values are shown by treatment and condition in Table 1.

*** FIGURE 3 NEAR HERE ***

Force

Within the study 68±14.7% of the subject's body weight on average (36.9kg) was placed on the force plate in the control condition. Within the treatment condition 50±12.6% of the body weight (27.2kg) was directed through the foam roller into the force plate on average. The difference between the treatment and control conditions mean force exerted was significant ($p<0.01$). Force exerted on the force plate (and roller) was similar between subjects across conditions ($p=0.21$). The treatment condition ranged from a force of 27% body mass to 67% and an absolute force of 15.8 to 40.6 kg. The correlation between the relative and absolute values for the treatment condition was $r=0.69$. The correlation between mass and average force in the treatment condition was $r=0.61$.

Reliability

The reliability of the flexibility assessment employed here has previously been assessed and analyses indicated the measure has good reliability.[30] Inter- and intratrial observations for TMG and thermography were all significantly correlated (all $p<0.05$). Inter- and intratrial reliability statistics for TMG and thermography are presented in Table 2 along with the smallest worthwhile change that may be useful for future studies.

TABLE 2 NEAR HERE

DISCUSSION

The aim of this investigation was to establish if a single bout of foam rolling affects flexibility, muscle contractility and temperature. The primary finding of this study was that foam rolling had no statistically significant effect on muscle contractility markers or temperature. While the overall flexibility was statistically greater in the treatment condition in practical terms this is insignificant as it is within the published coefficient of variation for the test (10.6%)[30] or in this case 12.48^{o}. The present study controlled for force applied to the limb as has been done previously,[39] making the end point of range of motion measurement objective, rather than subjective. This may be one reason why no change in ROM was seen.

Previous authors have suggested that the mechanism that foam rolling utilizes to have an effect is similar to massage although no definitive consensus regarding the exact mechanism exists.[4] A recent review has highlighted that while the performance effects of massage are limited (Hedges g=0.19), massage can be effective if the recovery interval is short especially in untrained subjects.[40] The current study attempted to examine a possible mechanism of foam rolling by monitoring temperature change and while objectifying the flexibility measure in order to attempt to gain greater insight into the induced muscular changes that occurred, as measured by TMG.

The current data indicate there is a small but significant change after the intervention of 1 x 60s bout of rolling. However, this may have little practical relevance for intervention. Other authors have used different repeated interventions (e.g. 3 x 60s[16]) without justification however, this may indicate that multiple bouts of foam rolling have a greater influence of the musculature due to a larger overall dose. Previous authors that examined flexibility measures, did not specify any pressure advice nor standardization for the participants and did not demonstrate a change in flexibility.[41,42] Others that have used greater forces have shown greater increases in flexibility in what seems to be a dose response relationship. Sullivan and colleagues utilized a limited force of 13kg and found an increase in hamstring ROM of 4.3% and when using a higher force (25% of body mass; ~20kg), Bradbury-Squires and colleagues demonstrated increases in knee-joint ROM by 10-16%.[13,43] There has been no direct comparison of different pressures, however, in the present study an average of 50% of body mass (27.2kg) was directed through the roller at the quadriceps. The authors of the current study did observe a range of forces being applied across subjects that differed in absolute terms. This is a potential source of variance – as is the change in load that is observed as the roller moves longitudinally across the muscle.[39]

This study utilized trained athletic subjects. Only one other study has investigated the effects of foam rolling utilizing athletes as the subject group.[44] Previous comparisons of the chronic effects of static stretching in trained and un-trained subjects have reported greater effects in untrained individuals[45] and this may therefore be a factor that could explain the lack of results reported both in this study and that of Mikesky and colleagues as trained athletes may already possess a greater ROM due to regular exercise and stretching and therefore if the flexibility is not compromised foam rolling would not induce an increase in ROM.

A criticism of the mechanistic approach of the current study may be drawn from the massage literature as this suggests that effects occur at the systemic whole-body level and as such designs that massage only one limb and use the contralateral as an internal control should be avoided.[46] The counter argument is that with the current research design the authors utilized a full control condition in order to detect the true difference of any intervention. The dependent variables in this research were more local than systemic in nature.

Previous literature has looked at foam rolling as an acute recovery intervention after inducing muscle damage. [2,10,47] In the current study an intervention was examined without a preceding bout of muscle damage. The reason for this was to try and separate the size of any effect of foam rolling itself on flexibility rather than an as an analgesic or increasing the compliance of injured muscle. While it is beyond the scope of this investigation to comment at length, the eccentric muscle damage induced in previous studies is not always like that encountered in athletes in training in terms of scope or mechanism. Also the acute use of foam rolling immediately post session is not as commonplace as its use as part of the warm up before the next session 24 or 48 hours later.[48]

While four studies have examined the time course of flexibility changes following myofascial release most are limited to 10 minutes post treatment.[1,7,47,49] Halperin and colleagues showed increased ROM at one and 10 minutes post intervention. MacDonald and colleagues reported increased ROM at two and 10 minutes post-intervention. One study looked at longer time periods and found no effect at 30 and 60 minutes post intervention, there was however an effect after 10 minutes, however the authors did not specify the duration of rolling on the hamstrings.[47] Only one study has observed no effect on flexibility at 10 minutes similar to this study. The study in question tested the plantar flexors and used a rolling protocol of 3 x 30s.[49]

Future directions

Future study in the area may utilize a larger relative dose (likely through a series of repeated reps) to see if this induces an effect. This dose-response relationship remains to be elucidated in order to scientifically influence practitioner's prescriptions.

While the dose response relationship of volume on flexibility is unclear, it appears that there is a greater effect with a greater force and most studies have found meaningful improvements with around 1-2 min of treatment.[4] While the load applied during rolling was measured, an approach could be taken to use the foam roller at a standardized load on the muscle relative to the subjects body weight, though his approach would likely see the subject be in a supine, passive position as the force is imposed on them rather than self-applied. As such this may not have as high a practical relevance. The dose response relationship seems clearer for force but again is an area for future investigation.

Additionally, measures of discomfort may need to be recorded during the rolling intervention as there may be a psychological effect for adolescent athletes who may experience discomfort during the intervention. Also, potentially without the discomfort being of a sufficient level they may not perceive it to have a benefit.[50,51] Any future investigation should utilize a standardized end point for testing flexibility or ROM that is objective rather than subjective.

The time course of the intervention was only followed up to 30 minutes post. Investigation of up to one hour post may be merited as athletes utilize foam rolling within their warm ups which can occur in excess of one hour prior to competition.[52,53]

CONCLUSION

Foam rolling had no practically significant effect on flexibility and no effect on muscle contractility markers or reflected temperature within 30 minutes of rolling. The present study controlled for force applied to the limb and observed no change in ROM.

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FIGURE TITLES

Figure 1: A. Foam roller used in intervention (Low & Flat section) **B.** Set up of subject on foam roller on force plate with points of contact (both forearms and foam roller)

Figure 2: Individual value plot of standardized differences to Pre condition based on condition (treatment or control). Mean values are marked.

Figure 3: Individual value plot of standardized differences to Pre condition based on condition (treatment or control). Mean values are marked as is a 1^0C line.