Article

Not peer-reviewed version

The Influence of Mobility Training on the Myofascial Structures of the Back and Extremities

Gunda Slomka , Robert Schleip * , Peter Frei , Michael Krämer , Nicolas Kurpiers , Katharina Bauermeister , Wolfgang Bauermeister

Posted Date: 3 November 2023

doi: 10.20944/preprints202311.0218.v1

Keywords: fascia research; connective tissue; range of motion; mobility training; shearwave elastographie; load compensation; well-being

Article

The Influence of Mobility Training on the Myofascial Structures of the Back and Extremities

Gunda Slomka [1], Robert Schleip [2,3,*], Peter Frei [4], Nicolas Kurpiers [4], Michael Krämer [5], Katharina Bauermeister [6] and Wolfgang Bauermeister [7]

1 Institute of Sport Science, University of Hildesheim, Universitätsplatz 1, 31141 Hildesheim, gundaslomka@gmx.de
2 Conservative and Rehabilitative Orthopedics, Department Sport and Health Sciences, Technical University of Munich, Campus D, Georg-Bauchle-Ring 60/62, 80992 München, Germany
3 Department of Medical Professions, Diploma Hochschule, 37242 Bad Sooden-Allen, Germany
4 Institute of Sport Science, University of Hildesheim, Universitätsplatz 1, 31141 Hildesheim, Germany; peter.frei@Uni-Hildesheim.de; kurpiers@uni-hildesheim.de
5 Institute for Materials Technology, Technical University Darmstadt, Grafenstrasse 2, 64283 Darmstadt, Germany; michael.kraemer@tu-darmstadt.de
6 Conservative and Rehabilitative Orthopedics, Department Sport and Health Sciences, Technical University of Munich, Campus D, Georg-Brauchle-Ring 60/62, 80992 München, Germany; katharina.bauermeister@tum.de
7 Department of Sports, Physical and Rehabilitative Medicine, Kharkiv National Medical University 4 Nauky avenue, Kharkiv, 61022, Ukraine; v.bauermayster@knmu.edu.ua
* Correspondence: robert.schleip@tum.de

Abstract: The subject of the study was the effect of a multicomponent program (Mobility Routine) on muscular and fascial stiffness, the flexibility, subjective well-being, and body perception. The assumption was that high physical stress affects myofascial structures and joint range of motion. Participants were sourced from the Special Police Operations Unit of Lower Saxony, Germany, and engaged in a 12-week intervention comprising thrice-weekly 30-minute sessions. The interventions consisted of Mobility Routine (MR) for the Intervention Group I and Crosstrainer Training (CT) for the Intervention Group II. The assessment of myofascial stiffness employed a Shear Wave Elastography. The joint flexibility, pressure pain threshold, and subjective experiences were documented. The results revealed increases in myofascial stiffness. In the CT group, fewer measurement areas showed a greater increase in stiffness compared to the MR group fewer areas showed a greater increase. MR demonstrated superior gains in flexibility compared to CT. Both groups experienced significant reductions in pain, tension, and discomfort. In conclusion repetitive motion patterns akin to CT lead to increased myofascial stiffness, while MR yields more balanced stiffness development, compensates for asymmetries, and improves body awareness. Hence, this study highlights the advantages of mobility training over Crosstrainer exercises and provides valuable insights for the recommendation of training regimens aiming at the enhancement of musculoskeletal functionality and overall well-being.

Keywords: fascia research; connective tissue; ultrasound elastography; range of motion (ROM); mobility training; prevention; load compensation; well-being

---

1. Introduction

Intense and unbalanced stresses in daily life lead to the development of muscular imbalances [1, 2]. Such imbalances in the myofascial or musculoskeletal system may be responsible for pain or for damage to vertebral as well as body joints and the soft tissues [3-11]. The present literature has documented the potential of exercise programs encompassing strength and stretching routines to effectively prevent injuries [11, 12]. Accordingly, the Association of Substitute Health Funds in Germany (VDEK) actively supports preventive exercise initiatives and certification bodies evaluate and endorse relevant course systems accordance with §20 of the Prevention Act. However, few concepts have an evidence-based proof regarding their preventive merits [13]. The Santa Monica Sports Medicine Foundation (SMSMF) and the Oslo Sports Trauma and Research Centre (OSTRC) developed a complete warm-up program in 2006 to prevent injuries in amateur soccer players. Study results show that the FIFA 11+ warm-up significantly prevents soccer injuries [14-16]. However, the general study situation on the effect of exercise programs as injury prevention is heterogeneous. Van Mechelen [17] could not present significant results of a warm-up program in terms of injury prevention in a study with runners, whereas a review by Woods et al. [18] describes the positive preventive effect of a warm-up routine directly before training. James et al. [19] highlight an anti-inflammatory effect of exercise in the autochthonous back muscles of animals (mice). Presently, there is no proof of the effect of a complex exercise program on changes in tissue stiffness or joint range of motion or compensation for imbalances. In health, fitness, competitive sports or even in therapy, exercise programs like Intervention Measure I (Mobility Routine / MR) are common and widely used. Despite this great popularity, scientific data is rare. Based on the anatomical and physiological results of fascial research, basic techniques for movement have been developed on which future research could build.

Myofascial stiffness, limitations in range of motion (ROM), imbalances are related to pain [20-28].

The research methods were used to investigate the following questions: Does a mobility training intervention change tissue stiffness, joint range of motion, and compensate for possible imbalances? Do the interventions influence the pressure pain threshold and the overall well-being?

2. Materials and Methods

2.1. Participants

A total of 73 individuals were initially enrolled in this research endeavor. They build an experimental cohort comprised of individuals subjected to considerable physical demands, specifically officers affiliated with the State Criminal Police Office and the Special Deployment Command (SEK) in Lower Saxony, Germany. Given their substantial weekly physical exertion (averaging 24.7 hours), these participants represent a clientele exposed to intense and potentially excessive physical stress. Five subjects were excluded from the study due to illness. All participants provided an updated medical fitness certificate (Erl. MiP 25.4-12506 v.20.12.2013, in the most current iteration). All participants signed an informed consent form prior to the study.

Cohort from the State Criminal Police Office / Special Deployment Command (SEK).

Table 1. Anthropometrical data for the cohort from the State Criminal Investigation Office/Special Operations Command (SEK).

Parameter	Intervention Group I (MR)	Intervention Group II (CT)
Number of Participants (n)	47	21
Gender (Male)	47	21
Age (years)	28.4 ± 4.6	29.1 ± 3.8
Weight (kg)	79.6 ± 9.3	81.2 ± 10.5
Height (cm)	181.5 ± 6.3	179.8 ± 5.9
Duration of Intervention (weeks)	12	12
Physical Workload (hours/week)	24.7 ± 2.9	24.5 ± 3.1
Weight of Protective Gear (kg)	33.5 ± 2.1	33.4 ± 2.3

Note: Data presented as mean ± standard deviation.

2.2. Intervention

The test group was divided into the Mobility Routine (MR /n=47) and Crosstrainer (CT/n=21) groups. Over a 12-week period, both groups exercised three times per week for 30 minutes. The MR-group performed video file guided mobility training based on six basic techniques. These basic techniques were developed based on anatomical, physiological, and pathophysiological assumptions regarding mechanisms of action as a working hypothesis. These techniques consist of exercises that aim to increase range of motion (1), to generate pressure variations (2), stretching exercises (3), to aid orientation to the myofascial lines (4), to increase of body heat (5) and to integrate rotational and shear motion techniques (6). Together, these six techniques form the basic framework of a 35-minute

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2023 doi:10.20944/preprints202311.0218.v1

MR workout. The control group (CT-group) completed a conventional Crosstrainer (CT) workout. Both groups trained with at least one day of intervention break between training sessions. The CT group was instructed to maintain contact with the handrail. The training intensity was set at a moderate level: basic endurance in GA 1, determined based on individual heart rate data that the subjects had already collected for their endurance training. Importantly, the exercise program of the comparison group focused exclusively on the basic techniques of warmth (5) and rotation and shear motion techniques (6). The main interest of the study was to investigate the effect of MR training on the myofascial structures of the body. Figure 1 provides an overview of the MR training.

Figure 1. Mobility Routine Flow A.

Figure 2. Mobility Routine Flow B.

Figure 3. Mobility Routine Flow C.

Figure 4. Crosstrainer Intervention Group II.

Note: For the 12-week intervention period, three Lifefitness crosstrainers (Elipsen crosstrainer of the company Lifefitness - series activate) were made available at the office. Other Crosstrainers from other manufacturers at other locations were allowed to be used.

All individual exercises are strung together to create an exercise flow. This flow is run through and routinized several times in the loop system before a new loop flow begins.

The entire Mobility Routine and background on the basic techniques can be read in the monograph accompanying this article (link to the monograph at the end of this article under: Data Availability).

2.3. Measurement Technique

Shear Wave Elastography (SWE) was the chosen method to assess shifts in tissue stiffness. Collecting quantifiable data for myofascial stiffness using SWE is a novelty in sports science and

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2023 doi:10.20944/preprints202311.0218.v1

sports therapy work[25, 27, 29]. To date, the method has been predominantly used in internal medicine and tumor diagnostics [30, 31]. It allows assessment of the stiffness of the myofascia at several centimeters' depth. The probe of the Resona 7 Ultrasound System (Mindray Bio-Medical Electronics Co., China) was positioned at the respective areas during examination, characterized by minimal tissue pressure and zero movement [32]. A pivotal metric in this analysis is the Motion Stability Index (M-STB), which gauges the extent of motion artifacts. The quality of measurements is described on a scale from 0 (indicating poor quality) to 5 (denoting optimal quality). For the purpose of measurements, exclusively cine recordings with a top-tier five-star rating were considered. Facilitating an expansive elastogram spanning several cm^2 (approximately 3.3 cm x 2.5 cm/large area), this device provides comprehensive insights. Young's Elasticity Modulus (E) serves as a metric to assess tissue stiffness, encompassing the entirety of the area of interest (indicated in kPa). The examination comprised twenty measurement regions spanning the trunk and extremities. Moreover, for the thoracolumbar fascia (TLF), the analysis was segregated into muscle and fascia components. Table 2 shows a total of 22 measurement regions.

Table 2. Measuring ranges - SWE[1].

	Region	Description	Subject-Position
1	M. trapezius Trap. L	10 cm paravertebral from the center of the cervical spine acromion	sitting
2	M. trapezius Trap R	10 cm paravertebral from the center of the cervical spine acromion	sitting
3	Plantar fascia PLF L	Calcaneus	prone position
4	Plantar fascia PLF R	Calcaneus	prone position
5	Thoracolumbar fascia TLF L4/5 L	Line ilium upper margin 2 cm paravertebral proc. spinous process	prone position
6	Thoracolumbar fascia TLF L4/5 R	Line ilium upper margin 2 cm paravertebral spinous process	prone position
7	M. gluteus medius GlutMed L	2.5 cm distal to the center of the crista iliac	prone position
8	M. gluteus medius GlutMed R	2.5 cm distal to the center of the crista iliac	prone position
9	M. gluteus maximus / GlutMax L	Midpoint between greater trochanter and sacrum	prone position
10	M. gluteus maximus / GlutMax R	Midpoint between greater trochanter and sacrum	prone position
11	M. biceps femoris BicFem L	20 cm from the fibula head in the direction Tuber ischiadicum	prone position
12	M. biceps femoris BicFem R	20 cm from the fibula head in the direction Tuber ischiadicum	prone position
13	M. gastrocnemius lateralis / Gastroc L	12 cm below the popliteal fossa, lateral calf	prone position
14	M. gastrocnemius lateralis / Gastroc R	12 cm below the popliteal fossa, lateral calf	prone position
15	Mm. adductor ADD L	20 cm from adductor tuberculum dist. femur towards the pubic tubercle	supine position
16	Mm. adductor ADD R	20 cm from adductor tuberculum dist. femur towards pubic tubercle	supine position
17	M. rectus femoris RFM L	0 cm from the upper edge of the patella in direction. Spina iliaca anterior superior (SIAS)	supine position
18	M. rectus femoris RFM R	0 cm from the upper edge of the patella in direction. Spina iliaca anterior superior (SIAS)	supine position
19	M. tibialis anterior TibA L	9 cm below the patella, 1 finger width lateral to the margo anterior of the tibia	supine position

[1] The measurement positions were determined individually reproducibly on the basis of anatomical features using centimeter measures.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2023 doi:10.20944/preprints202311.0218.v1

20	M. tibialis anterior TibA L	9 cm below the patella, 1 finger width lateral to the margo anterior of the tibia	supine position

The values of the different stiffnesses are color-coded in the elastogram (Figure 4). Warm colors indicate measurement areas with low elasticity (high stiffness), while the cold colors represent soft tissue.

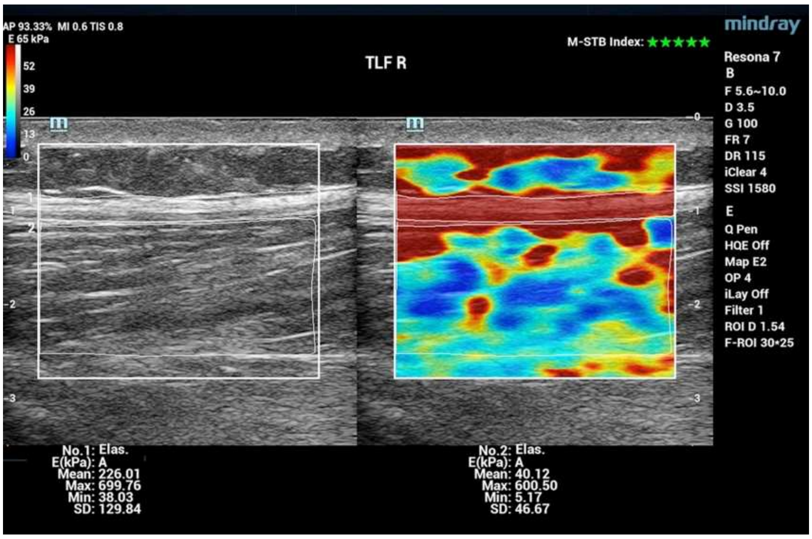

Figure 5. SWE Tracing and Color code. Note: Measurement region thoracolumbar fascia (TLF) and erector spinae muscle (ESp) right; left: B-scan mode; right: SWE; manual division of a measuring region into two measuring ranges: TLF and ESp; indication of elastic modulus (E) in kPa as Mean (average value), Max (maximum value), Min (minimum value) and SD (standard deviation).

In order to display individual structures such as the TLF separately from the muscle (measuring range: ESp), the measuring ranges are calculated separately by tracing.

This separation was not made for all other measurement ranges.

Joint mobility assessment was executed utilizing the Deluxe Inclinometer sourced from Performance Attainment Associates (Roseville, Minnesota, USA). This cutting-edge device incorporates a gravitational goniometer enhanced with fluid-damped ball technology, thereby enabling meticulous and friction-free measurements. In particular, the Cervical Range of Motion Instrument (C-ROM) was enlisted to assess rotational, lateral flexion, flexion and extension movements of the cervical spine. Simultaneously, the Back Range of Motion Instrument (B-ROM) played an important role in quantifying lateral flexion and rotation while maintaining an upright spinal posture. Moreover, the instrument facilitated the evaluation of foot flexibility (dorsiflexion) and hip joint mobility through the Leg Flexion-extension test.

During trunk flexion, the Finger-to-Floor Distance (FFD) measurement was conducted utilizing a vertical measuring board (Flex Board) affixed to a standing platform. The deepest point of the fingers was ascertained in centimeters, with the reference line (0-line) aligned with the platform's height. Similary, the Heel-to-Buttock Distance (HBD) was quantified in centimeters using a ruler.

The achievement of uniform pressure application was secured by integrating the MicroFet2TM Pressure Sensor, ensuring precision within a measurement accuracy range spanning from 3.6 Newtons (N) to 1320 N. For determining the distance from the heel to the buttocks, a constant force of 80 Newtons (N) was consistently applied to the shin.

The pressure pain threshold was measured with an algometer (hand force precision measuring device) from the company TesT GmbH in Newton 320.1 (N). Values were determined for two body regions (measuring range trap and TLF) and analyzed in side-by-side comparison. Measurements were performed by the same investigator at the beginning and at the end of the 12-week intervention.

Participants' well-being was evaluated through a questionnaire, and intrapersonal comparisons were conducted using the Numeric Pain Rating Scale (NPRS). The NPRS scale (Numeric Pain Rating Scale) is a widely used method for subjective assessment of pain intensity. The measurement procedure is considered validated [33-35]. To streamline the analysis of pain, tension, and discomfort

 doi:10.20944/preprints202311.0218.v1

responses on the 0-10 NPRS scale 35 body regions were rated in a range of 0-10 at baseline and after completion of the intervention. For statistical evaluation and intraindividual comparative analysis, the data were reduced to two statements:

There is a state of discomfort
(all statements from 1 – 10 were included in the evaluation).
There is an intense state of discomfort
(all statements greater than 5 were included in the evaluation).

3. Results

A number of 68 participants were available for evaluation.

3.1. Shear Wave Elastography (SWE)

Among the 22 investigated regions, alterations in the stiffness of both muscles and fascia were observed in 17 regions as a result of the MR training. Notably, the measurement area of the trapezius muscle (Trap) exhibited the most significant change (ΔE) as shown in Table 3.

Table 3. Changes in Elastic Modulus (T1 to T2) - MR Group[2].

Measurement Area	ΔE (%)	p-Value
M. trapezius		
Trap Left	+48	<0.001
Trap Right	+61	<0.001
Mm. Adductor		
ADD Left	+36	<0.001
ADD Right	+29	<0.001
M. biceps femoris		
BicFem Left	+19	<0.001
BicFem Right	+43	<0.001
M. gluteus medius		
GlMed Left	+25	<0.001
GlMed Right	+13	0.007
M. gastrocnemius lateralis		
GaLat Right	+18	<0.001
Thoracolumbar fascia		
TLF Left	+15	0.039
TLF Right	+17	0.003
M. erector spinae		
ESp Left	+15	0.001
ESp Right	+14	<0.001
M. biceps femoris		
RFM Left	+7	0.012
RFM Right	+17	<0.001
M. gluteus maximus		

[2] The table displays the measurement areas (L = left, R = right) in the MR group T1/T2 (n = 47), where a significant change in the elasticity modulus ΔE was observed. A '+' before E indicates an increase, while a '–' indicates a decrease. The significance level (p-value) is 0.05.

Measurement Area	ΔE (%)	p-Value
GlMax Right	+10	0.006
M. anterior tibialis		
TibA Left	-9	0.014

It needs to be noted that Table 3 presents the percentage difference in median values between T1 and T2 specifically for the MR group. The utilization of the median as the reference value was based on the absence of normal distribution in all measurement areas. It is important to highlight that certain measurement areas did not exhibit any notable changes in stiffness.

For 13 out of 22 measurement areas, the CT training induced alterations in the stiffness of muscles and fascia as shown in Table 4.

Table 4. Changes in Elastic Modulus (T1 to T2) - CT Group.

Measurement Area	ΔE (%)	p-Value
M. rapezius		
Trap Left	+94	<0.001
Trap Right	+77	<0.001
Thoracolumbar fascia		
TLF Left	+44	<0.001
M. biceps femoris		
RFM Right	+35	0.001
Mm. adductor		
ADD Left	+31	<0.001
ADD Right	+40	0.002
M. gastrocnemius lateralis		
GaLat Right	+31	0.007
GaLat Right	+31	0.007
M. biceps femoris		
BicFem Left	+31	0.002
BicFem Right	+31	<0.001
M. gluteus maximus		
GMax Right	+19	0.004
M. erector spinae		
ESp Left	+0.9	0.010
M. gluteus medius		
GlMed Left	+0.6	0.019

Table 4 comprises the difference between T1 and T2 for the CT group in median values. Similarly to the MR group, within the CT group, there were also measurement areas without notable alteration in stiffness. These specific areas with a relatively stable stiffness are omitted in the table.

The ΔE values of all 22 measurement areas of both groups were compared to evaluate stiffness changes of the myofascia.

Table 5. Change in Elastic Modulus (T1 to T2) - MR-CT Comparison[3].

[3] The table shows the comparison of ΔE for the MR and CT groups.

 doi:10.20944/preprints202311.0218.v1

Measurement Area	ΔE (%) MR	ΔE (%) CT	MR > CT CT > MR
M. Biceps femoris			
BicFem R	+43	+40	MR > CT
Mm. adductor muscle			
ADD R	+29	+18	MR > CT
M. gluteus medius muscle			
GlMed L	+25	+6	MR > CT
Thoracolumbar fascia			
TLF R	+17	+10*	MR > CT
M. erector spinae			
ESp L	+15	+9	MR > CT
ESp R	+14	+5*	MR > CT
M. gluteus medius			
GlMed R	+13	0*	MR > CT
M. rectus femoris			
RFM L	+7	0*	MR > CT
M. trapezius			
Trap L	+48	+94	CT > MR
Thoracolumbar fascia			
TLF L	+15	+44	CT > MR
M. gastrocnemius lateralis			
GaLat L	+9*	+31	CT > MR
M. rectus femoris			
RFM R	+17	+35	CT > MR
M. trapezius			
Trap R	+61	+77*	CT > MR
Mm. adductor			
ADD L	+36	+50	CT > MR
M. gastrocnemius lateralis			
GaLat R	+18	+31	CT > MR
M. anterior tibialis			
TibA L	-9	+5*	CT > MR
M. biceps femoris			
BicFem L	+19	+31	CT > MR
M. gluteus maximus			
GlMax R	+10	+19	CT > MR
M. anterior tibialis			
TibA L	-9	+5*	CT > MR
M. gluteus maximus			

The * indicates that the difference value is based on a parametric distribution of the baseline data.

Measurement Area	ΔE (%) MR	ΔE (%) CT	MR > CT CT > MR
GlMax L	-7	0*	CT > MR
M. anterior tibialis			
TibA R	+5*	+7*	CT > MR
Plantar fascia			
PLF L	0*	1*	CT > MR
Plantar fascia			
PLF R	-9*	-8*	CT > MR

Note: For eight measurement areas (Rows 1-8), the MR group exhibited a larger ΔE than the CT group. Conversely, for 14 measurement areas (Rows 9-22), the ΔE in the CT group was higher. CT training appears to increase stiffness to a greater degree.

3.2. Range of Motion (ROM)

For all 27 measurement areas of the body and spinal joints, ΔROM significantly increased in the MR group.

Table 6. Change of ROM T1 T2 - MR Group[4].

Measurement Area	MT1	MT2	ΔROM absolute (° / cm)	ΔROM relative (%)	p-Value (<0.05)
Finger-Floor Distance					
FBA	4*	9*	5*	133	0.000
Hip Internal Rotation					
Hip IR R	20	28	8	40	0.000
Foot Dorsiflexion 0°					
Do 0° R	13	18	5	38	0.001
Foot Dorsiflexion 90°					
Do 90° R	22	30	8	36	0.001
Hip Internal Rotation					
Hip IR L	25	32	7	28	0.000
Spinal Rotation					
WS Rot L	30	38	8	27	0.028
Foot Dorsiflexion 0°					
Do 0° L	12	15	3	25	0.000
Heel-Glute Distance					
FGA R	15	12	3*	20	0.000
Heel-Glute Distance					
FGA L	14.5	12	3*	17	0.000

[4] Table 6 displays the Range of Motion (ΔROM) for the MR group, consisting of 47 participants. The absolute results are presented in degrees or centimeters (* indicated in centimeters), while the relative results are expressed in percentages. A total of 27 measurement areas were analyzed, of which thirteen were bilateral in nature (significance level= 0.05).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2023 doi:10.20944/preprints202311.0218.v1

Measurement Area	MT1	MT2	ΔROM absolute (° / cm)	ΔROM relative (%)	p-Value (<0.05)
Leg Extension					
LegExt L	62	72	10	16	0.000
LegExt R	62	72	10	16	0.000
Shoulder Internal Rotation					
Shoulder IR L	55	62	7	13	0.000
Shoulder External Rotation					
Shoulder AR R	76	85	9	12	0.000
Shoulder Internal Rotation					
Shoulder IR R	59	65	6	10	0.001
Shoulder External Rotation					
Shoulder AR L	82	89	7	9	0.001
Hip External Rotation					
Hip AR L	39	42	3	8	0.008
Spinal Lateral Flexion					
WS Latflex L	39	42	3	8	0.000
Spinal Rotation					
WS Rot R	30	32	2	7	0.024
Cervical Spine Flexion					
C-spine Flexion	59	63	4	7	0.000
C-spine Lateral Flexion					
C-spine Latflex R	40	42	2	5	0.000
Cervical Spine Lateral Flexion					
C-spine Latflex L	42	44	2	5	0,003
Cervical Spine Rotation					
C-spine Rot R	70	73	3	4	0,000
Hip External Rotation					
Hip ext. rot. R	43	44	1	2	0,000
Cervical Spine Extension					
C-spine Extension	78	79	1	1	0,028
Cervical Spine Rotation					
C-spine Rot L	79	78	0	0	0,031
Cervical Spine Lateral Flexion					
C-spine Latflex R	45	45	0	0	0,000
Foot Dorsiflexion 90°					
Foot d-flex 90° L	20	20	0	0	0,003

Table 6 presents the absolute and relative changes (ΔROM) between T1 and T2 for the MR Group, encompassing diverse measurement areas. The ΔROM in the Finger-Floor Distance measurement displays a substantial change of 5 centimeters (133%). Additionally, Hip Internal Rotation exhibits notable changes (ΔROM of 8°/40% for the right hip and 7°/28% for the left hip). Moreover, the Heel-

Buttock Distance (FGA) shows improvements of 3 centimeters (20%) and 17% on both sides, while a consistent increase of ΔROM in Leg Extension was measurable for both sides by 10°/16%.

A total of 16 areas out of 27 measurement areas pertaining to the body and spinal joints, exhibited significant ΔROM alterations within the CT group from T1 to T2 as illustrated in Table 7.

Table 7. Change of ROM T1 T2 - CT group[5].

Measurement Area	MT1	MT2	ΔROM absolute (° / cm)	ΔROM relative (%)	p-Value (<0.05)
Finger-Bottom Distance					
FBA	3.6	7	3*	94	0.000
Hip Internal Rotation					
Hip IR R	20	26	6	30	0.050
Hip IR L	24	31	7	29	0.000
Heel-Buttock Distance					
FGA R	16	13	3*	19	0.000
Shoulder Internal Rotation					
Shoulder IR L	53	61	8	15	0.001
Heel-Buttock Distance					
FGA L	16.5	15	2*	12	0.002
Shoulder External Rotation					
Shoulder ext. rot L	81	88	7	9	0.004
Shoulder int. rot. R	57	62	5	9	0.014
Cervical Spine Flexion					
C-spine Latflex	59	64	5	8	0,021
Foot Dorsiflexion 90°					
Foot do-fl 90° L	17	18	1	6	0.018
Shoulder External Rotation					
Shoulder ext. rot. R	79	84	5	6	0.036
Spinal Lateral Flexion					
Spine Latflex L	40	42	2	5	0.001
Spine Latflex R	39	41	2	5	0.001
Cervical Spine Rotation					
C-spine Rot L	70	73	3	4	0.005
C-spine Rot R	70	72	2	3	0.029
Foot Dorsiflexion 0°					
Foot do-fl 0° L	11	11	0	0	0.019

[5] Table 7 illustrates the Range of Motion (ΔROM) for the CT group, comprising 21 participants. The results are presented in degrees or centimeters (* indicated in centimeters), while relative results are expressed in percentages. A total of 27 measurement areas were analyzed, with thirteen of them being bilateral (significance level=0,05).

Changes in ΔROM of 6° and 7° (30% and 29%) in hip internal rotation were observed for the right and the left side respectively. Minor symmetrical changes in spinal lateral flexion (WS Latflex) and cervical spine rotation (HWS Rot) were also identified on both sides (WS Latflex 2°/5%). For the within-individual side comparison (ΔROMRL) another contrast occurs between the intervention groups (MR/CT). In the MR group, ΔROMRL exhibited a decrease in eight out of twele measurement areas. Conversely, three measurement areas showed an increase in ΔROMRL. In the CT group, ΔROMRL decreased in two out of twelve measurement areas, whereas it increased in seven measurement areas. In general, the changes in ROM within the CT group were less pronounced, in terms of both the number of measurement areas and the extent of ΔROM, compared to the MR group.

3.3. Pressure Pain Threshold (PPT)

The measurement area "Trap" demonstrated a parametric distribution within the participant group, which encompassed 68 individuals. The assessment of ΔPPT did not yield any statistically significant results neither for the MR group (n=47) nor the CT group (n=21).

Table 8. Table 1 Change of pressure pain threshold T1 T2 – Trapezius muscle.

Measurement Area	ΔPPT (N) T1 -T2 MR	p-Value (<0.05)	ΔPPT (N) T1 -T2 CT	p-Value (<0.05)	ΔPPT (N) T1 -T2 MR-CT
Trapezius muscle					
Trap L	-3	0,420	+2	0,530	-MR +CT
Trap R	+1	0,696	-4	0,726	+MR -CT

The measurement area "TLF" exhibits a normal distribution within the total participant group, which included 68 individuals. Significant changes were noted within the MR group (N=47), wheras no significant changes were observed within the CT group (N=21). Negative values mean an increase in sensivity, positive values a decrease accordingly.

Table 9. Change of pressure pain threshold T1 T2 – thoracolumbar fascia.

Measurement Area	ΔPPT (N) T1 -T2 MR	p-Value (<0.05)	ΔPPT (N) T1 -T2 CT	p-Value (<0.05)	ΔPPT (N) T1 -T2 MR-CT
Thoracolumbar fascia					
TLF L	-22,4	0,002	-3,4	0,741	-MR -CT
TLF R	-24	0,001	-12	0,308	-MR -CT

The implementation of the Mobility Routine yielded a significant enhancement in pressure sensitivity within the TLF (thoracolumbar fascia). The pressure pain threshold decreased. Changes in pressure pain thresholds were observed across all measurement ranges, however, a statistical significance was only achieved within the TLF measurement area as illustrated in Table 9. Negative values display an increase in sensivity and vice versa.

3.4. Well-Being

The sensitivity data are subjective assessments on a scale of 0-10. Each individual evaluated a comprehensive set of 35 body regions. The percentage alterations for each sensitivity aspect (Δtension, Δpain, Δdiscomfort) were systematically examined and analyzed. Table 10 shows the changes in each sensitivity (Δtension, Δpain, Δcomfort) for all indications from 1-10 on the NPRS and for the indications related to the changes in severe discomfort (≥ 5).

Table 10. Changes in sensitivity T1 T2 - MR-CT.

	ΔTension (%)		ΔPain (%)		ΔDiscomfort (%)	
	1-10	≥ 5	1-10	≥ 5	1-10	≥ 5
decrease						
MR	73	72	72	86	72	82
CT	58	75	80	83	71	100
increase						
MR	20	24	16	7	11	29
CT	26	0	7	17	9	0
no change						
MR	7	4	12	7	17	9
CT	16	25	13	0	9	0

The subsequent bar charts in figure 1 visually represent the percentage changes (Δ) for all sensitivities.

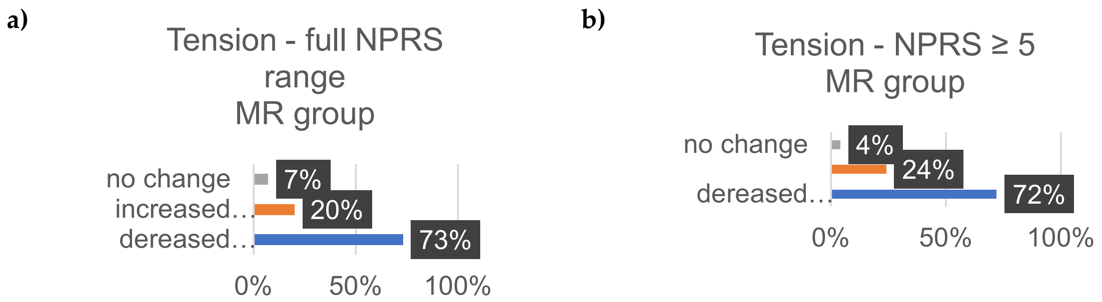

Figure 1. This bar chart depicts the alterations in sensitivity to tension within the MR group. Panel (a) offers a comprehensive view of all ratings ranging from 0 to 10 on the NPRS (Numeric Pain Rating Scale). In contrast, panel (b) shows values of ≥ 5 on the NPRS.

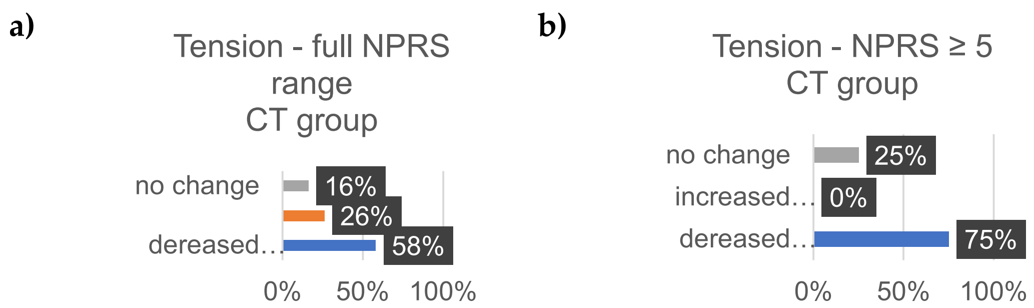

Figure 2. The provided bar chart illustrates the changes in sensitivity to tension within the CT group. Panel (a) provides a holistic representation of all ratings spanning from 0 to 10 on the NPRS. Conversely, panel (b) exclusively displays values ≥ 5 on the NPRS.

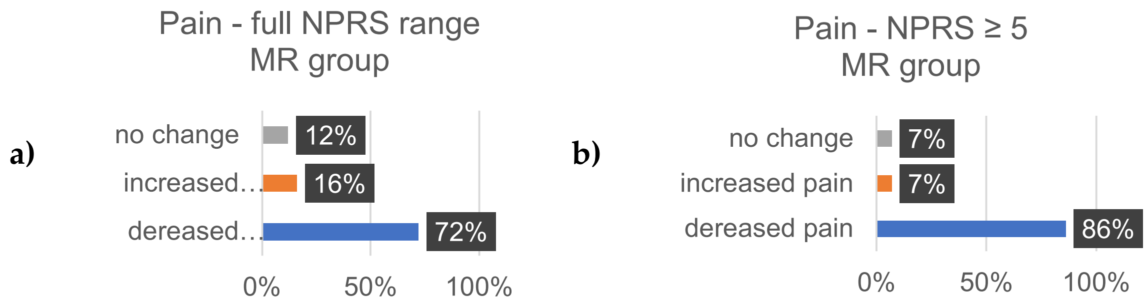

Figure 3. The provided bar chart illustrates the changes in sensitivity to pain within the MR group. Panel (a) provides a holistic representation of all ratings spanning from 0 to 10 on the NPRS. Conversely, panel (b) exclusively displays values ≥ 5 on the NPRS.

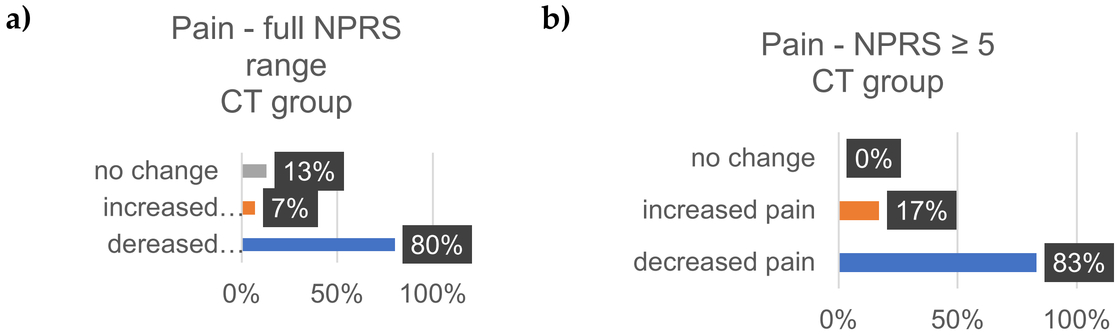

Figure 4. The provided bar chart illustrates the changes in sensitivity to pain within the CT group. Panel (a) provides a holistic representation of all ratings spanning from 0 to 10 on the NPRS. Conversely, panel (b) exclusively displays values ≥ 5 on the NPRS.

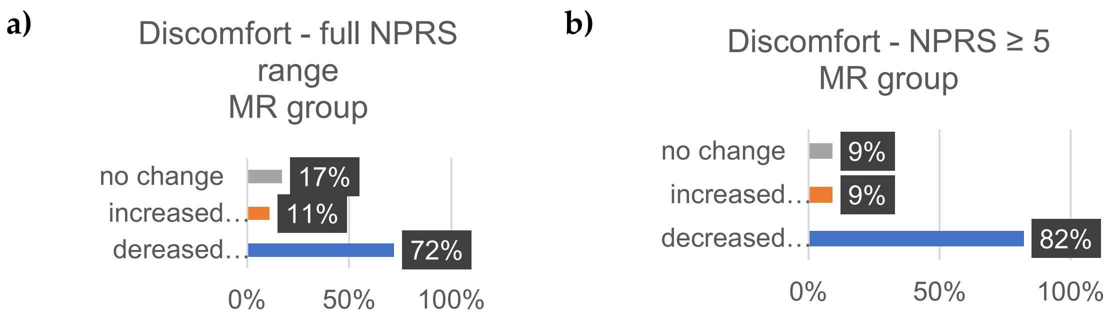

Figure 5. The provided bar chart illustrates the changes in sensitivity to discomfort within the MR group. Panel (a) provides a holistic representation of all ratings spanning from 0 to 10 on the NPRS. Conversely, panel (b) exclusively displays values ≥ 5 on the NPRS.

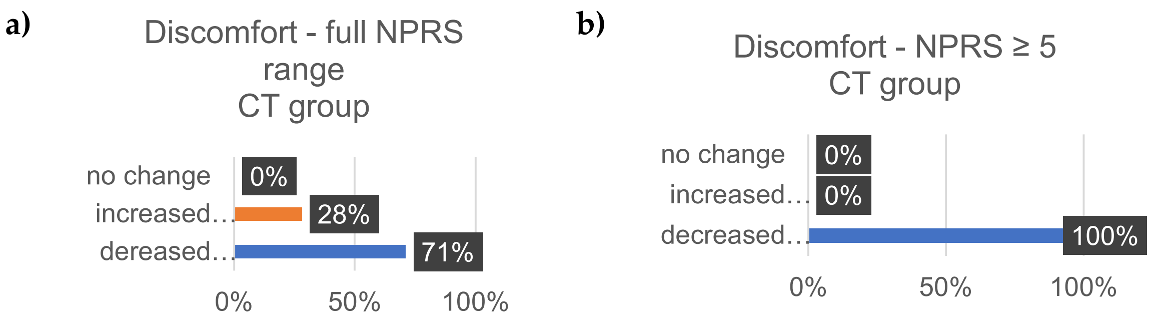

Figure 6. The provided bar chart illustrates the changes in sensitivity to discomfort within the CT group. Panel (a) provides a holistic representation of all ratings spanning from 0 to 10 on the NPRS. Conversely, panel (b) exclusively displays values ≥ 5 on the NPRS.

In summary, according to the stated perception both interventions led to improved well-being. In the MR group, all values for the increase in well-being were above 72%. Striking were the high percentage values for the decrease of individual intense pain perception and discomfort (86% / 82%) in the MR group. In the CT group, the perception of general overarching tension decreased proportionally by only 58%. The data for the reduction of intense discomfort could not be included in the evaluation because only one subject provided information. A correlation with the results of the other measurement methods could not be established.

4. Discussion

The objective of this study was to assess the impact of a diverse mobility training program (referred to as Mobility Routine - MR) on alterations in tissue stiffness, mobility, and subjective well-being. To analyze the effects of mobility training on the myofascial structures in the back and extremities, we used the special unit of the State Criminal Investigation Department as the study group. This group was divided into two intervention groups as the study progressed. The results can make a valuable contribution to injury prevention, pain and tension reduction, performance enhancement, health maintenance and promotion of subjective well-being. The mobility exercise program for the MR group mobilizes, strengthens, and stretches based on the anatomy, physiology, and pathophysiology of muscles and fascia [43, 44]. In the following sections of this paper, the respective results will be discussed in detail and be related to the different loading standards.

Elastic Modulus Analysis:

The assessment of the Myofascial Elastic Modulus (E) revealed a notable increase in myofascial stiffness in both intervention groups. The increase in E in the CT group was more pronounced for fewer measurement ranges. This is possibly due to a more constistent and cyclic loading by repetitive movements patterns and thus fewer body regions beeing exposed to higher stress levels in CT training. In the MR group, E was moderately increaseed for a greater number of measurement areas, indicating a constistent response across sides.

The current data base for the analysis of myofascia using SWE is poor. Accordingly, there is a lack of reference values of E (in kPa) that would allow for an evaluation of the results. The greater increase in E for fewer measurement ranges in the CT group suggests that repetitive movements of the same kind result in greater tissue stiffness. More studies and development of comprehensive data sets would allow for assessments of the absolute value of E. For the current study, the results were analyzed in the intraindividual comparison of T1 to T2 and in the side-to-side comparison (right-left / RL). The data collected are used for basic research and are considered to contribute to a better assessment and evaluation of the absolute value of E in the future.

Earlier works [3, 6, 7] have elucidated how unilateral adaptations, manifested as imbalances, predispose individuals to discomfort and increased susceptibility to injuries. The sample population of the current study displayed a noticeable number of measurement areas with inter-individual imbalances in the right-left comparison at T1. Given the participants' classification as a physically highly active cohort, it is conceivable that intense physical stress contributes to varying tissue stiffness in this comparison. The objective was to ascertain whether the interventions could mitigate existing myofascial imbalances. However, the outcomes exhibited heterogeneity. Only in the case of one measurement area (ADD) the MR group demonstrated a significant reduction (-20%) in right-left disparity. This result could potentially be linked to significantly improved mobility outcomes for the hip.

Nevertheless, no statistically significant correlation was established. In the CT group, a reduction in side-to-side differences was evident for two measurement areas, TLF (-46%) and ESp (-6%). TLF seems to be particularly affected during CT training. Despite substantial differences in ΔE for TLF (44% left / 10% right), indicating significant yet uneven adaptation, values converged in the right-left comparison by T2. In the ESp area, the increase in ΔE was modest (9% left / 5% right), yet even in this

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2023 doi:10.20944/preprints202311.0218.v1

measurement area, the right-left difference decreased. CT training seems to excel in addressing lumbar imbalance. The divergence between sides was equalized with a significant increase in E.

The Elastic Modulus for thigh muscles (M. biceps femoris / BicFem) showed a significant increase in both intervention groups (33.75 ± 10). Similarly, ΔERL also showed a significant increase in both groups. Notably, the CT group gained a 23% increase. While CT training demonstrated the potential to compensate for imbalances in TLF and ESp, it appears to exacerbate imbalances in the stiffness of leg extensor muscles.

An unusually high ΔE was observed in the neck muscles for the CT group (Trap - 94% left / 77% right). In the MR group, ΔE in the Trap area also increased by 48% and 61%. No significant compensation of ΔERL was noted.

Range of Motion (ROM)

The MR training led to improvements in joint mobility across body and spinal joints and was superior over CT training concerning Range of Motion (ROM) and the number of affected measurement areas (MR: 27/27; CT: 16/27). The alignment of intra-individual right-left disparities further solidified the superiority of MR training. In eight out of twelve (only the bilateral measuring ranges were considered) measurement areas, a reduction in intra-individual right-left differences was observed. MR training proved to be significantly more effective than CT training in compensating for imbalances. For instance, MR training contributed to balancing side-to-side differences in the hip, whereas CT training accentuated the asymmetry between body sides.

In this study no significant correlation was detected between Shear Wave Elastography (SWE) and ROM results.

Pressure Pain Threshold (PPT)

The measurement of the pressure pain threshold (PPT) was conducted on two specific body regions, specifically the lower back (TLF) and the upper edge of the trapezius muscle (Trap). The results in the trap measurement area were rather inconsistent as it was difficult to determine by the subject and thereby heterogeneous and not significant. Contrary to the initial assumption, the PPT exhibited a decrease in TLF for both sides (left and right) within both the MR and CT groups. However, this reduction in PPT was statistically significant only within the MR group. In a broader context, the determination of the PPT indicates that the interventions led to an increased sensitivity to pressure in the TLF. Given the high density of receptors, the TLF is recognized as one of the most pain-sensitive structures in the lower back.

Well-Being

The analysis of the questionnaire yielded significant reductions in the perception of tension, pain, and discomfort. In the MR group, discomfort decreased by more than 76%±6, while a similar reduction of 73%±11 was observed in the CT group. Only small increases in discomfort (MR: 15%±9; CT: 16%±10) were observed.

Both interventions led to a significant enhancement in individual well-being, with MR training showing a slightly more pronounced effectiveness than CT training. Multiple studies [36-39] affirm the relationship between exercise and pain reduction. The key lies in selecting a kind of movement with moderate intensity, as intense exertion can contribute to the accumulation of pro-inflammatory cytokines associated with the development of disease and pain [40-43].

It is worth delving into why MR training resulted in a lowered PPT in the TLF, signifying an earlier perception of pressure-induced pain, while simultaneously enhancing the participants' subjective well-being by alleviating tension, pain, and discomfort. In contrast to CT training, MR training was likely associated with an improved level of body awareness, involving somatic mindfulness and higher sensitivity of mechanoreceptors. This could potentially explain why participants in the MR group generally exhibited greater sensitivity to sensory changes in the body. The amplified perception of pressure or tension might also extend to other body regions beyond the specifically measured area.

Interestingly, the neck region was frequently associated with tension and pain in the well-being questionnaire. Throughout the intervention from T1 to T2, participants reported improved well-being. Elevated tissue stiffness in this region does not appear to correlate with pain and tension perception.

 doi:10.20944/preprints202311.0218.v1

In fact, pain and tension decreased with increasing E. However, significant correlations were not identified. In future studies, exploring the correlation between E levels and painless states, as well as investigating the relationship between pain, tension, and tissue stiffness, could provide valuable insights.

A Bonferroni correction was not applied to the results for SWE, ROM, and PPT because these were individual, unrelated measurements that did not mutually influence each other.

5. Conclusions

The clearest results of the four examination methods were seen in the increase in mobility. The ROM increased significantly in the MR group for all 27 measurement areas. The assumption that MR training causes an increase in ROM was confirmed. In the CT group, ROM increased in 16 of 27 measurement areas. MR training was shown to be superior to CT training in terms of increasing mobility. Also, when comparing the absolute numbers of mobility increase, the difference of increase (degree in %) is higher in the MR group than in the CT group. In addition, MR training proved to be a harmonizing technique for imbalances in the intraindividual right-left comparison. MR training was shown to be superior to CT training. To reduce mobility restrictions and to compensate for asymmetries of the ROM in the right-left comparison, the Mobility Routine seems to be an appropriate measure.

Shear wave elastography (SWE) represents the influence of the interventions on tissue stiffness. For the MR group, an increase in elastic modulus (E) was analyzed for 17 of 22 measurement areas, contrary to the formulated hypothesis. In the CT group, 13 out of 22 measurement areas were found to be stiffer at T2 than at T1. It seems that physical stress has an effect on tissue stiffness. As a function of exercise, the modulus of elasticity (E) increases. Comparing the percent change, E increased more moderately and homogeneously in the MR group than in the CT group. The MR training seems to have a more homogeneous effect on the measurement regions than the CT training with a consistent, repetitive motion character, possibly due to the high variance of the exercises. Presently, individuals serve as their own control systems. To establish reference values for absolute levels of E across subjects or cohorts, it is imperative to create larger databases. Currently, it remains uncertain how much tension, stiffness, and elasticity are optimal and appropriate for different body regions in terms of health, performance, and pain relief. This study's results contribute to the foundational data collection through a substantial measurement volume (22 measurement ranges x 68 test subjects) to facilitate the establishment of standard values for diverse body regions in the future. A conclusive assessment regarding the corrective effects of the interventions on existing lateral asymmetry could not be made. Only four out of eleven measurement regions displayed significant outcomes. In three measurement regions, side differences converged, specifically in the ADD measurement region for the MR group and in the TLF and ESp measurement regions for the CT group. These preliminary findings offer a positive starting point that can potentially be expanded with longer intervention durations if necessary. A significant correlation between the increase in mobility and the increase in tissue stiffness was not observed.

In the future, it would be advantageous to compute E values separately for muscle and deep fascia in all measurement regions. Currently, technical limitations restrict us to a two-dimensional calculation of the measurement regions. A three-dimensional analysis would provide valuable insights. Additionally, calculating E across the entire length of the muscle would be beneficial. Given the volume of data, only one region per measurement area has been computed in this study.

The intervention-induced changes in pressure pain threshold (PPT) revealed significant findings within the TLF measurement area for the MR group. Notably, the thoracolumbar fascia displayed an increased sensitivity to pressure following the 12-week intervention. It seems that MR training has a sensitivity-enhancing impact on the TLF, which is known to have a high nerve density[44, 45]. This may result in a lowered stimulus threshold for mechanoreceptors, while nociceptors appear to respond with a heightened stimulus threshold. To enhance the statistical significance of these findings, it would be beneficial to assess PPT across multiple regions. However, in this study, priority was given to SWE and ROM determination, and due to time constraints, PPT assessment was limited to two regions.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2023 doi:10.20944/preprints202311.0218.v1

The analysis of the subjective well-being questionnaire demonstrated a significant overall improvement in general well-being. Across the board, there was a reduction of more than 70% in the perception of tension, pain, and discomfort.

The impact of mobility training on the myofascial structures of the back and extremities can be summarized as follows:

Mobility training (MR) significantly enhances the mobility of all measured areas.

MR has a harmonizing effect, reducing imbalances in range of motion (ROM).

MR consistently lowers tissue stiffness.

MR heightens the sensitivity of the thoracolumbar fascia (TLF) to pressure.

MR increases subjective well-being and diminishes sensations of tension, pain, and discomfort.

With the increasing comprehension of the fascial system, the future holds the potential to incorporate crucial preventive, regenerative, and rehabilitative components into existing movement and treatment paradigms. A more comprehensive grasp of fascial system physiology, as well as an understanding of the role of tissue overload and inflammation, should be a central focus of forthcoming sports science research.

As early as 2007, Langevin [46] postulated that specific movement patterns like exercise therapy and yoga could potentially reverse fascial tissue misalignments. Furthermore, Berrueta et al. (2016) [47] demonstrated the anti-inflammatory effects of stretching in rats, while James et al. (2018) [19] highlighted the reduction of inflammatory cytokines through exercise on the multifidii muscle in humans.

This present study substantiates the impact of mobility training on myofascial tissues. The initial hypothesis posited that tissue overload induced by strenuous exercise alters tissue stiffness, restricts range of motion, adversely affects well-being, and poses long-term harm to the body. The results of this intervention study offer compelling evidence that mobility traininghas the potential to positively mitigate the repercussions of intense physical demands, including imbalances, movement restrictions, and sensitivities.

The abundance of inflammatory cytokines within the tissue appears to be a pivotal factor influencing tissue stiffness, mobility restrictions, and well-being disturbances such as pain or tension [36, 37, 40, 42, 43, 48-50]. Future studies, potentially involving the monitoring of changes in the number of inflammatory cytokines and immune cells like macrophages, monocytes, or eosinophils in the blood count, could elucidate the threshold of exercise intensity that leads to pathogenic consequences and identify which movements promote salutogenesis at what intensity and scope.

To ensure the robustness of the findings and further validate the Mobility Routine, additional cohorts of participants should be investigated. For example, a test series with a randomized cohort or individuals with nonspecific, repetitive, or chronic back pain would complement the existing test results. A comprehensive validation of the Mobility Routine could have significant implications in preventive and rehabilitative contexts and substantially expand existing treatment approaches (1:1 system/patient: therapist). This would empower individuals, whether they are athletes or patients, to independently or with the guidance of a sports instructor or sports therapist, proactively and effectively mitigate interfering factors and take measures against overload and injuries.

Similarly, it might be interesting to investigate whether the intervention (MR) has a different impact on older subjects than on younger subjects.

Follow-up studies with different cohorts could help to promote and maintain health and performance. Larger samples, intervention groups of equal size, or even a control group undergoing different mobility training with different basic techniques would be beneficial to achieve more scientific power.

Research into the fascial system holds substantial promise for future investigations. In the realms of prevention, pain management, injury prevention, and performance enhancement, increased knowledge stands to unveil new, expansive, and complementary resources for both training and therapy. Striving for a comprehensive understanding of the physiology and pathophysiology of the fascial system is desirable. This understanding could enable the precise targeting of performance-enhancing training stimuli, support the body's salutogenesis, and mitigate tissue overloads and injuries resulting from physical activity in sports and leisure activities.

 doi:10.20944/preprints202311.0218.v1

Author Contributions: G.S.: Study leader, study design, study execution, development of the Mobility Routine, author of the monograph. R.S.: Consultant for selecting measurement techniques, advisor from the Fascia Research Group. P.F.: Supervisor and advisor throughout the study, doctoral supervisor. N.K.: Research assistant, co-author of the article. M.K. Statistical analysis. K.B.: Conducted a comparative study on SWE; defined the SWE measurement areas. W.B. Supervisor and advisor throughout the study, doctoral supervisor, conducted SWE measurements for all participants at T1 and T2, traced and analyzed the elastograms. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the University of Hildesheim, Department 1 under reference number 138 (received on 28 April 2020). The study protocol was registered with the German Clinical Trials Register (DRKS00032581).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The research paper, including all data sets, is available for public inspection in the library of the Foundation University of Hildesheim (https://doi.org/10.25528/099).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Weishaupt, P., R. Obermüller, and A. Hofmann, *[Spine stabilizing muscles in golfers].* Sportverletzung Sportschaden : Organ der Gesellschaft fur Orthopadisch-Traumatologische Sportmedizin, 2000. 14(2): p. 55-58.
2. Maus, U., et al., [Comparison of trunk muscle strength of soccer players with and without low back pain]. Z Orthop Unfall, 2010. 148(4): p. 459-65.
3. Glick, J.M., *Muscle strains: prevention and treatment.* The Physician and sportsmedicine, 1980. 8(11): p. 73-77.
4. Lew, P.C., J. Lewis, and I. Story, Inter-therapist reliability in locating latent myofascial trigger points using palpation. Manual Therapy, 1997. 2(2): p. 87-90.
5. Weishaupt, P., R. Obermüller, and A. Hofmann, *[Spine stabilizing muscles in golfers].* Sportverletz Sportschaden, 2000. 14(2): p. 55-8.
6. LaStayo, P.C., et al., Eccentric muscle contractions: their contribution to injury, prevention, rehabilitation, and sport. J Orthop Sports Phys Ther, 2003. 33(10): p. 557-71.
7. Witvrouw, E., et al., Muscle Flexibility as a Risk Factor for Developing Muscle Injuries in Male Professional Soccer Players:A Prospective Study. The American Journal of Sports Medicine, 2003. 31(1): p. 41-46.
8. Paternostro-Sluga, T. and C. Zöch, *[Conservative treatment and rehabilitation of shoulder problems].* Radiologe, 2004. 44(6): p. 597-603.
9. Dexel, J., C. Kopkow, and P. Kasten, [Scapulothoracic dysbalance in overhead athletes. Causes and therapy strategies]. Orthopade, 2014. 43(3): p. 215-22.
10. Langevin, H.M., et al., Effect of Stretching on Thoracolumbar Fascia Injury and Movement Restriction in a Porcine Model. Am J Phys Med Rehabil, 2018. 97(3): p. 187-191.
11. Zemková, E., O. Poór, and M. Jeleň, Between-side differences in trunk rotational power in athletes trained in asymmetric sports. J Back Musculoskelet Rehabil, 2019. 32(4): p. 529-537.
12. Bourne, M.N., et al., An Evidence-Based Framework for Strengthening Exercises to Prevent Hamstring Injury. Sports Med, 2018. 48(2): p. 251-267.
13. McHugh, M.P. and C.H. Cosgrave, To stretch or not to stretch: the role of stretching in injury prevention and performance. Scand J Med Sci Sports, 2010. 20(2): p. 169-81.
14. Owoeye, O.B.A., et al., Efficacy of the FIFA 11+ Warm-Up Programme in Male Youth Football: A Cluster Randomised Controlled Trial. Journal of Sports Science & Medicine, 2014. 13(2): p. 321-328.
15. Bizzini, M. and J. Dvorak, FIFA 11+: an effective programme to prevent football injuries in various player groups worldwide-a narrative review. Br J Sports Med, 2015. 49(9): p. 577-9.
16. Silvers-Granelli, H., et al., *Efficacy of the FIFA 11+ Injury Prevention Program in the Collegiate Male Soccer Player.* The American Journal of Sports Medicine, 2015. 43(11): p. 2628-2637.
17. van Mechelen, W., et al., Prevention of running injuries by warm-up, cool-down, and stretching exercises. Am J Sports Med, 1993. 21(5): p. 711-9.
18. Woods, K., P. Bishop, and E. Jones, *Warm-up and stretching in the prevention of muscular injury.* Sports Med, 2007. 37(12): p. 1089-99.
19. James, G., et al., Dysregulation of the Inflammatory Mediators in the Multifidus Muscle After Spontaneous Intervertebral Disc Degeneration SPARC-null Mice is Ameliorated by Physical Activity. Spine (Phila Pa 1976), 2018. 43(20): p. E1184-e1194.
20. Bauermeister, W., Pesavento, Andreas, Real Time Elastographie of Fascia and Myofascial Trigger Points, in Seminar Series Triggerpoint-Shockwave Therapy. 2000, Sportschule Hennef Germany.

21. Langevin, H.M., et al., Reduced thoracolumbar fascia shear strain in human chronic low back pain. BMC Musculoskelet Disord, 2011. 12: p. 203.
22. Drakonaki, E.E., G.M. Allen, and D.J. Wilson, *Ultrasound elastography for musculoskeletal applications.* Br J Radiol, 2012. 85(1019): p. 1435-45.
23. Botanlioglu, H., et al., Shear wave elastography properties of vastus lateralis and vastus medialis obliquus muscles in normal subjects and female patients with patellofemoral pain syndrome. Skeletal Radiology, 2013. 42(5): p. 659-666.
24. Boettner, C., Interrater reliability of ultrasound elastography to examine stiffness and elasticity of muscles and fascia of the lower extremity in healthy adults. 2018, Technical University Munich Germany.
25. Creze, M., et al., Shear wave sonoelastography of skeletal muscle: basic principles, biomechanical concepts, clinical applications, and future perspectives. Skeletal Radiol, 2018. 47(4): p. 457-471.
26. Koppenhaver, S., et al., Reliability of ultrasound shear-wave elastography in assessing low back musculature elasticity in asymptomatic individuals. J Electromyogr Kinesiol, 2018. 39: p. 49-57.
27. Bauermeister, W., Ultraschall Elastografie. Stellenwert in der Sportmedizin. Sportärztezeitung, 2019. 02.
28. Hvedstrup, J.K., L.T.; Schytz, M.A.; Schytz, H.W., Increased neck muscle stiffness in migraine patiens with ictal neckpain: A shear wave elastography study. International Headache Society, 2020.
29. Dubois, G., et al., Reliable Protocol for Shear Wave Elastography of Lower Limb Muscles at Rest and During Passive Stretching. Ultrasound in Medicine & Biology, 2015. 41(9): p. 2284-2291.
30. Evans, A., et al., Invasive Breast Cancer: Relationship between Shear-wave Elastographic Findings and Histologic Prognostic Factors. Radiology, 2012. 263(3): p. 673-677.
31. Frulio, N. and H. Trillaud, *Ultrasound elastography in liver.* Diagn Interv Imaging, 2013. 94(5): p. 515-34.
32. Eby, S.F., et al., *Validation of shear wave elastography in skeletal muscle.* Journal of Biomechanics, 2013. 46(14): p. 2381-2387.
33. Hawker, G.A., et al., Measures of adult pain: Visual Analog Scale for Pain (VAS Pain), Numeric Rating Scale for Pain (NRS Pain), McGill Pain Questionnaire (MPQ), Short-Form McGill Pain Questionnaire (SF-MPQ), Chronic Pain Grade Scale (CPGS), Short Form-36 Bodily Pain Scale (SF-36 BPS), and Measure of Intermittent and Constant Osteoarthritis Pain (ICOAP). Arthritis Care Res (Hoboken), 2011. 63 Suppl 11: p. S240-52.
34. Williamson, A. and B. Hoggart, *Pain: a review of three commonly used pain rating scales.* J Clin Nurs, 2005. 14(7): p. 798-804.
35. Ferreira-Valente, M.A., J.L. Pais-Ribeiro, and M.P. Jensen, *Validity of four pain intensity rating scales.* Pain, 2011. 152(10): p. 2399-2404.
36. Karstoft, K. and B.K. Pedersen, *Exercise and type 2 diabetes: focus on metabolism and inflammation.* Immunol Cell Biol, 2016. 94(2): p. 146-50.
37. Pillon Barcelos, R., et al., Oxidative stress and inflammation: liver responses and adaptations to acute and regular exercise. Free Radic Res, 2017. 51(2): p. 222-236.
38. Simpson, R.J., et al., *Exercise and the Regulation of Immune Functions.* Prog Mol Biol Transl Sci, 2015. 135: p. 355-80.
39. Farzanegi, P., et al., Mechanisms of beneficial effects of exercise training on non-alcoholic fatty liver disease (NAFLD): Roles of oxidative stress and inflammation. Eur J Sport Sci, 2019. 19(7): p. 994-1003.
40. Barr, A.E. and M.F. Barbe, Inflammation reduces physiological tissue tolerance in the development of work-related musculoskeletal disorders. J Electromyogr Kinesiol, 2004. 14(1): p. 77-85.
41. Franceschi, C. and J. Campisi, Chronic inflammation (inflammaging) and its potential contribution to age-associated diseases. J Gerontol A Biol Sci Med Sci, 2014. 69 Suppl 1: p. S4-9.
42. Shah, J.P., et al., Biochemicals associated with pain and inflammation are elevated in sites near to and remote from active myofascial trigger points. Arch Phys Med Rehabil, 2008. 89(1): p. 16-23.
43. Matsuda, M., Y. Huh, and R.R. Ji, Roles of inflammation, neurogenic inflammation, and neuroinflammation in pain. J Anesth, 2019. 33(1): p. 131-139.
44. Mense, S. and U. Hoheisel, Evidence for the existence of nociceptors in rat thoracolumbar fascia. J Bodyw Mov Ther, 2016. 20(3): p. 623-8.
45. Mense, S., *Muskeln, Faszien und Schmerz*, ed. 1. 2021: Thieme Verlag.
46. Langevin, H.M. and K.J. Sherman, Pathophysiological model for chronic low back pain integrating connective tissue and nervous system mechanisms. Med Hypotheses, 2007. 68(1): p. 74-80.
47. Berrueta, L., et al., Stretching Impacts Inflammation Resolution in Connective Tissue. J Cell Physiol, 2016. 231(7): p. 1621-7.
48. Bjørklund, G., et al., Does diet play a role in reducing nociception related to inflammation and chronic pain? Nutrition, 2019. 66: p. 153-165.
49. Correa-Rodriguez, M., et al., Dietary Inflammatory Index Scores Are Associated with Pressure Pain Hypersensitivity in Women with Fibromyalgia. Pain Med, 2019.
50. França, M.E.D., et al., Manipulation of the Fascial System Applied During Acute Inflammation of the Connective Tissue of the Thoracolumbar Region Affects Transforming Growth Factor-β1 and Interleukin-4 Levels: Experimental Study in Mice. Front Physiol, 2020. 11: p. 587373.

 doi:10.20944/preprints202311.0218.v1