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Posted Date: 31 May 2024

doi: 10.20944/preprints202405.2122.v1

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Article

Immediate Effects of Wearing an Ankle Bandage on Fine Coordination, Proprioception, Balance and Gait in Patients with an Acute Ankle Injury

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Abstract: Ankle sprains are the most frequently occurring musculoskeletal injuries among recreational athletes. Ankle support through bandages following the initial orthotic treatment might be beneficial for rehabilitation purposes. Since hardly any study has investigated the impact of bandages in the acute phase of ankle sprains, our study examined the immediate effects of wearing an ankle bandage on fine coordination, proprioception, and motor performance in subjects five weeks after an acute ankle injury. In total, 70 subjects with acute unilateral supination trauma were tested. All subjects completed several rating questionnaires and biomechanical investigations, including a fine coordination and proprioception test, single leg stances, the Y-Balance test and gait analysis. All biomechanical investigations were conducted for the subject's injured leg with and without a bandage (MalleoTrain® Bauerfeind AG) and the healthy leg. Subjects reported moderate to strong improvements in ankle stability and pain when wearing the bandage. Wearing the bandage significantly normalized subjects' single leg stance performance, as well as the stance phase duration, and the vertical ground reaction forces during walking. However, the bandage did not have a clear effect on fine coordination and proprioception. Wearing a bandage in the acute phase of an ankle sprain may immediately improve motor performance, including standing and walking.

Keywords: acute ankle sprain; ankle joint; ankle bandage; soft ankle orthoses; fine coordination and proprioception; single leg stance; Y-balance test; modified Star Excursion Balance test; gait; rehabilitation

1. Introduction

The ankle is a complex joint with three degrees of freedom that enables the body to adapt to different surfaces during physical activities and to absorb shocks and forces. During running and jumping, those forces can reach multiple times the body weight [1,2]. Consequently, the ankle joint is one of the most stressed joints of the body, which can cause pain from injuries, such as fractures or sprains [3–5]. Ankle sprains mostly occur following uncontrolled, sudden movements, such as plantarflexion and inversion, which can lead to excessive force or strain in the ligaments of the joint. As a consequence, various ligamentous structures can be damaged, whereas the intensity of the trauma determines, whether it results in a strain or a rupture [4,6–9]. Depending on the injured ligaments involved, three types of ankle sprains can be distinguished: medial, lateral, and syndesmotic [9–11].

Nevertheless, sprains do not only affect components of the musculoskeletal system, but also damage various components of the proprioceptive system [3,9,12–17]. This includes damage of specialized receptors, which are located in muscles, tendons, ligaments, and the joint capsule, such as Golgi tendon organs, muscle spindles, joint receptors and various mechanoreceptors. As these receptors provide important information about muscle length, muscle contraction speed, muscle

 doi:10.20944/preprints202405.2122.v1

tension, and joint position, for planning, adapting and executing movements, any disruption may negatively affect motor control [13–15,18–22].

Ankle sprains are classified by severity and duration. Severity is ranked in three grades based on the extent of tissue damage, assessed through radiological and clinical examinations. Although there exist different classifications, duration is categorized as acute (up to 4 days post-injury), subacute (1 to 8 weeks post-injury), and chronic (more than 8 weeks post-injury). However, the exact timing for developing chronic ankle instability (CAI) is still debated [9,23,24].

From an epidemiological point of view, ankle sprains are the predominant type of injury among recreational athletes in various sports, accounting for approximately 49% of all injuries [5,6]. This includes non-contact sports, such as volleyball and running, as well as contact sports, such as basketball, handball and soccer [5,9]. The lateral ligamentous structures of the ankle joint are mostly affected, which account for approx. 85% of the cases [9–11,24–28]. Due to its high incidence, ankle sprains account for at least 14% of all emergency hospital visits, potentially even higher considering that 50% of individuals with ankle injuries do not report or seek hospital treatment [4,7,29–31]. As those study results underline the excessive incidence of ankle sprains, as well as the high impact on the economic and the healthcare system, an effective treatment, preferably in the acute and subacute phase seems crucial.

The standardized treatment algorithm for high-grade (grade 2 & 3) ankle sprains describes with all-day orthotic treatment for at least 5 weeks accompanied by active and passive physiotherapy [10,11,27,28,32]. The orthosis should be semi-rigid and stabilize the ankle joint. Therefore, it provides mechanical support and controls the range of motion (ROM) of the ankle joint [33–35]. Moreover, it enhances proprioceptive acuity, due to stimulating cutaneous mechanoreceptors, and joint receptors by compressing the underlying musculoskeletal structures [12,36,37]. In case of inadequate therapeutic support, residual symptoms, including pain, giving way, and impaired proprioception and neuromuscular control, can lead to chronic ankle instability (CAI) in 40 to 75% of individuals with ankle sprains [3,8,38–41]. In the worst-case scenario, CAI increases the risk of articular damage and the development of osteoarthritis. Additionally, it leads to substantial therapy costs and has a dramatic impact on patients quality of life [42,43].

An additional bandage treatment following the 5-week orthotic therapy could be advantageous in supporting the healing process and mitigating the risk of reinjury and the development of CAI. However, most studies that have investigated the effects of bandages on ankle sprains have primarily focused on healthy subjects or patients with CAI, with very limited research examining the effects of bandages during the acute or subacute phases of the injury. Therefore, the aim of our study was to investigate the immediate effects of wearing an ankle bandage on fine coordination, proprioception, and motor performance, five weeks after orthotic treatment in patients with acute lateral ankle sprains. We hypothesized that wearing the bandage helps to reduce pain and improve fine coordination and proprioception. Moreover, it may also enhance motor performance, such as improving quasi static and dynamic balance performance, as well as normalizing gait.

2. Materials and Methods

2.1. Participants

In total, 70 subjects with an acute ankle sprain, caused by unilateral supination trauma (minimum grade 2) were recruited for this study. Subjects were included with an age 18-60 years and if they presented the injury within a maximum of three days after the incidence at the Hospital Chemnitz (Germany). Exclusion criteria comprised grade 1 ankle sprain, upper leg sprain occurring within the last 12 months, acute concomitant osseous injuries, a history of a confirmed lateral ligament injury, CAI or neurological dysfunction, concomitant diseases of the affected upper leg (rheumatism, gout, arthrosis, surgery in past), use of anticoagulants or corticosteroids, and other injuries or diseases affecting motor performance and proprioception. If the patients were still suffering from the injury two to three weeks after the trauma, they were included in the study on a voluntary basis. After the initial treatment with orthotic supply according to the guidelines [10,11],

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the follow-up examination was performed approximately five weeks post-injury. This involved extensive clinical examination of the ankle joint (swelling, tenderness over the lateral ligament complex, and pain perception), followed by questionnaires and biomechanical investigations. Prior to the examination, all subjects were informed about the purpose of this study and provided written informed consent. All procedures were conducted according to the recommendations of the Declaration of Helsinki and were approved by the Ethics Committee of the Faculty of Behavioural and Social Sciences of Chemnitz University of Technology (V-320-17-LN-MalleoTrain-07042019).

2.2. Experimental Setup and Data Acquisition

All biomechanical investigations were conducted for subjects injured leg and the healthy leg with and without bandage in a randomized order, to minimize the influence of fatigue and habituation. Prior to the main trails, all subjects performed various test trials in order to become familiar with the bandage and the task. All tests were carried out barefoot. The bandage, which was used in this study (MalleoTrain® Bauerfeind AG), consisted of an elastic but tight-fitting high-low knit. Therefore, it exerts an alternating pressure massage during moving.

2.2.1. Subjective Ratings

Prior to the biomechanical investigations, the patients provided their anthropometric data, as well as indicating the pain they experienced when walking and standing barefoot, in shoes, with and without bandage. Afterwards, patients rated pain and stability improvements due to wearing the bandage during the biomechanical tests completing visual analogue scales (0 to 10). Additionally, patients reported whether the bandage provided improvements during the execution of different biomechanical tests.

2.2.2. Fine Coordination and Proprioception Test

A customized foot pedal was implemented to examine the fine coordination and proprioception of the ankle joint. The pedal was designed to allow for inversion and eversion movements of the foot with a maximum range of 5°, respectively (Figure 1A). A target sine wave was presented on a screen in front of the subject, moving from the right to the left side of the screen with a velocity of approx. 7 cm/s. All subjects were instructed to trace the target sine wave as accurately as possible by moving the pedal with inversion and eversion movements of the foot. The extent of the target sine wave ranged from 3° inversion to 3° eversion (Figure 1B). To ensure high test quality, the rotation center of the ankle joint was aligned vertically with the pivot point of the pedal. Additionally, subjects' lateral side of the lower leg must have maintained permanent contact with the device to guarantee that the ankle joint and not the hip joint performed the movement (Figure 1A). Five trials each lasting 18 s were performed for each testing condition. The mean deviation from the target sine wave from trial four and five within the time interval 6-16 s was calculated for further statistical analysis.

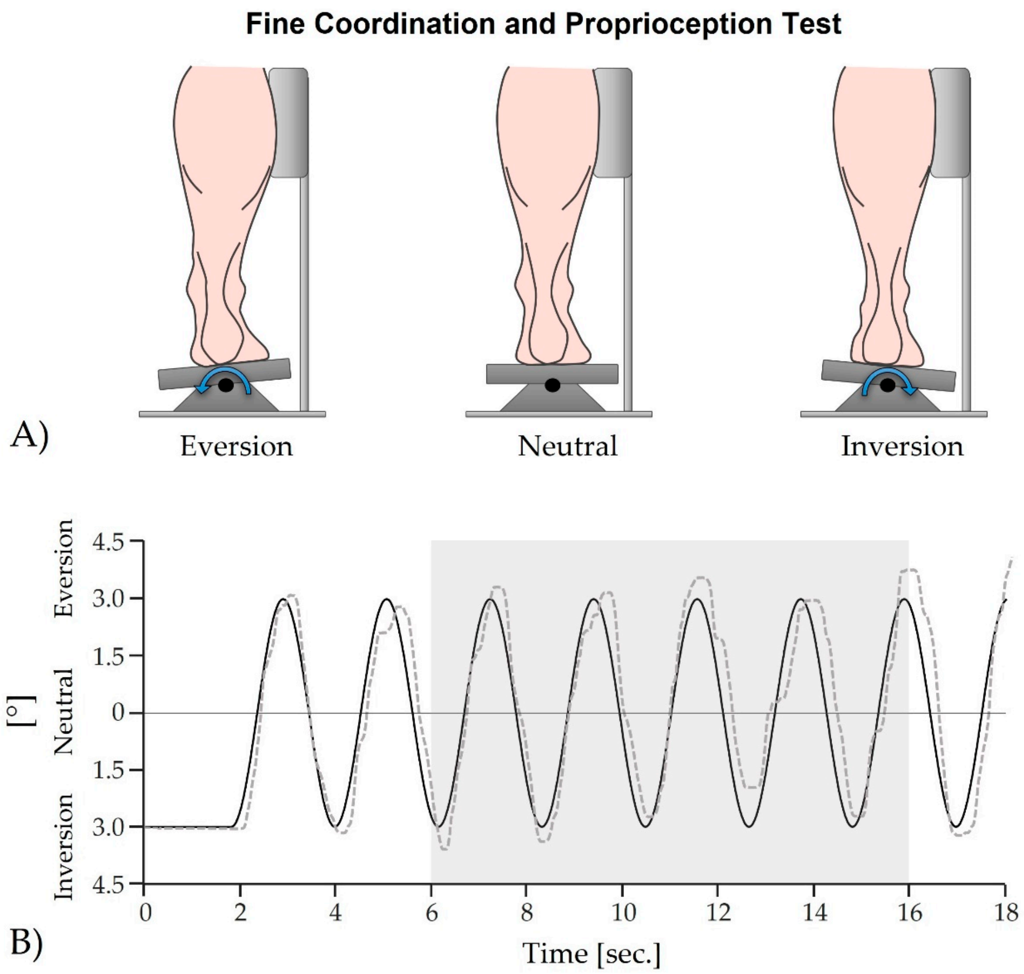

Figure 1. Fine coordination and proprioception test; A) Hardware: Foot pedal for inversion and eversion movements of the ankle joint; B) Software: Target sine wave (solid black line) which gets traced by a random subject, which was wearing the bandage (dashed grey line). The grey box indicates the analysed area, in which the mean deviation between both signals was calculated.

2.2.3. Single Leg Stance (Quasi-Static Postural Stability)

Subjects' quasi-static postural stability was quantified while performing single leg stances using a pressure distribution platform (Zebris FDM 1.5; Isny, Germany, sampling frequency 100 Hz). Subjects had to stand as still as possible with an upright posture, keeping the knee of the stance leg straightened but not locked, both arms crossed in front of the chest, and directing their gaze ahead. For each subject one trial, lasting 20 s was collected for each testing condition, respectively. For further statistically analysis, the center of pressure (COP) parameters COP length and 95% COP confidence area were calculated for each of the mentioned conditions.

2.2.4. Y-Balance Test (Dynamic Postural Stability)

The Y-Balance test, also known as the modified Star Excursion Balance Test (mSEBT) was used to assess subjects' dynamic postural stability [12,44–49]. The test quantifies the ability to maintain a stable base of support, while reaching as far as possible with the lower limbs. To perform the test, subjects stood with one foot in the centre of the measuring grid, ensuring that it was precisely aligned with the grid lines (Figure 4). Thereafter, subjects had to reach out their unloaded foot in one of the three directions (anterior, posterior-medial or posterior-lateral), attempting to reach the furthest point possible, before returning to the starting position. The examiner marked this point and measured the distance from the centre of the grid. If any subject exerted excessive weight on the reaching limb, moved their stance foot from the starting position, or lost balance, the trial had to be repeated. To minimize the influence of inter-individual anthropometrical data, the maximum reach distance was normalized to subjects' individual leg length (Gribble et al. 2003). All subjects completed three main trials for each direction for the three testing conditions healthy stance leg, injured stance leg with and without bandage.

2.2.5. Gait

For subjects' safety, the pressure distribution platform was integrated in a walk way to be level with the ground. Subjects were instructed to walk at least ten times over the platform (sampling frequency 100 Hz), to collect sufficient data. Gait speed had to be quick but comfortable and safe, and could be chosen individually. For all testing conditions, spatial-temporal gait parameters, such as gait velocity and step length were exported from the Software Zebris winFDM (version 0.1.11, Isny, Germany). Additionally, from the curve of the vertical ground reaction force, the first and second peaks, as well as the relative durations of the single stance phase and double stance phase, were identified for further statistical analysis (Figure 2).

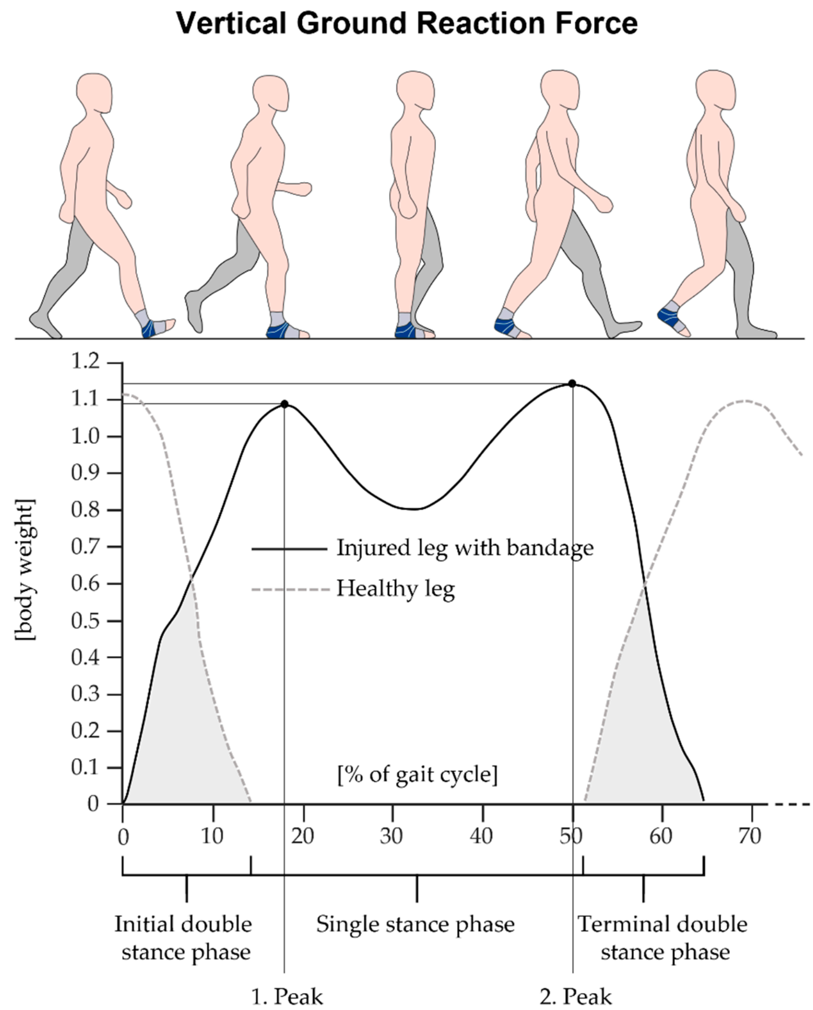

Figure 2. Illustration of an actual vertical ground reaction force curve during walking from a random subject. The black solid line indicates the curve of the ground reaction force for the injured leg with a bandage, while the grey dashed line indicates the curve for the healthy leg. Shown are the first peak, corresponding to the loading response, and the second peak, corresponding to the terminal stance phase of the gait cycle [50]. The illustration also displays the relative duration of the single stance phase and both double stance phases (grey area). Note that for the statistical analysis, the relative double stance phase is the sum of both the initial and terminal double stance phases.

2.3. Statistical Analysis

Mean and standard deviations (mean ± SD) were calculated for all biomechanical variables. Given that the variables were normally distributed according to the Shapiro–Wilk test, a one-way analysis of variance (ANOVA) for repeated measurements followed by the Bonferroni post-hoc test was used to determine whether differences existed between the three conditions healthy leg and the injured leg with and without bandage. Statistical significance was set at $\alpha = 0.05$ for all analyses. In addition, effect size (Cohen's d) was calculated to quantify the magnitude of differences when statistical significance was found. The coefficients were interpreted as trivial ($d < 0.2$), small ($d < 0.5$), medium ($d < 0.8$), or large effects ($d \geq 0.8$).

3. Results

3.1. Demographic and Clinical Data:

As shown in Table 1, the gender and the side of the injured leg were distributed almost evenly. There were slightly more male subjects and injuries of the right leg. The most frequently structures of the ankle joint with pressure pain were the anterior talofibular ligament, followed by calcaneofibular ligament and the posterior talofibular ligament. Those injuries were accompanied frequently by swelling and other complaints.

Table 1. Demographic and clinical data (structures of the ankle joint with pressure pain), presented as mean ± SD.

Age [years]	Height [cm]	Weight [kg]	Gender	Side of the injured leg	Pain rating	Instability rating
34.8±11.8	173.3±10.1	78.7±16.4	male 36; female 34	left 32; right 38	1.6 ± 1.3	3.0 ± 2.2
Injured structures of the ankle joint			n	Relative n to total number of subjects (70) [%]		
Anterior talofibular ligament			54	84.4		
Posterior talofibular ligament			31	48.4		
Calcaneofibular ligament			38	59.4		
Swelling			53	82.8		
General complaints			61	95.3		

Prior to the investigations, the patients generally reported mild to moderate pain, whereas during walking they felt more pain compared to standing. Wearing the bandage, generally eased pain (Table 2). Walking barefoot or in shoes did not reveal major differences for subjective pain perception.

Table 2. Self-rated pain perception of the injured ankle joint (visual analogue scale from 0 to 10). Data are presented as mean ± SD, minimum and maximum.

pain	**walking barefoot**	**standing barefoot**	**walking in shoes**	**standing in shoes**	**walking with bandage**	**standing with bandage**
mean ± SD	1.60 ± 1.58	1.13 ± 1.45	1.69 ± 1.45	1.09 ± 1.27	1.18 ± 1.46	0.88 ± 1.25
range [Min Max]	[0 7]	[0 7]	[0 6]	[0 5]	[0 6]	[0 6]

Various improvements have been reported by the subjects due to wearing the bandage (Figure 3). While one half of the cohort reported from strong stabilizing effects when wearing the bandage, the other half reported rather moderate stabilizing effects. Pain was improved mostly moderate. For the biomechanical investigations most self-reported improvements due to wearing the bandage were found for the single leg stance and the Y-Balance test. The fine coordination and proprioception test, as well as the gait test also showed improvements, however a notable number of patients reported from no improvements when wearing the bandage.

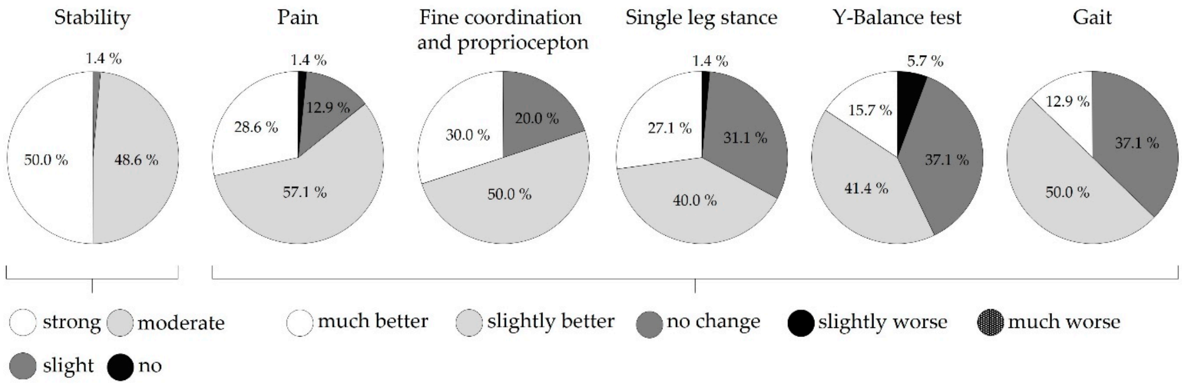

Figure 3. Self-ranked improvements due to wearing the bandage, data presented as percentage of n.

3.2. Fine Coordination and Proprioception Test:

For the fine coordination and proprioception test, no statistically significant differences were found between any condition. However, there was a trend towards smaller deviations, especially for the injured leg with the bandage compared to the healthy leg (Table 3).

Table 3. Comparison of the deviation value between the target sine wave and the signal drawn by the subjects between all three conditions healthy leg, injured leg with and without bandage. Data presented as mean ± SD.

Parameter	healthy leg	Injured leg without bandage	Injured leg with bandage	p-value	d
Mean deviation [°]	1.30 ± 0.5	1.26 ± 0.5	1.20 ± 0.5	0.078	-

3.3. Single Leg Stance (Quasi-Static Postural Stability):

As presented in Table 4, statistically significant differences between study conditions could only be found for the COP length, however not for the COP 95% confidence area. Subjects showed especially longer COP excursions for the injured leg without bandage compared to the injured leg when wearing the bandage and the healthy leg. Nevertheless, the COP 95% confidence area showed the same result as the COP length, however as a trend and not statistically significant.

Table 4. Comparison of the COP parameters between all three conditions healthy leg, injured leg with and without bandage. Data presented as mean ± SD.

Parameter	healthy leg	Injured leg without bandage	Injured leg with bandage	p-value	d
COP length [mm]	470.0 ± 115.9 a	548.8 ± 145.1 a;b	477.5 ± 106.7 b	< 0.001 a < 0.001 b < 0.001	1.1 a 0.60 b 0.56
COP 95% confidence area [mm²]	217.6 ± 101.5	238.2 ± 91.1	216.3 ± 79.0	0.263	-

3.4. Y-Balance Test (Dynamic Postural Stability):

The Y-Balance test revealed higher values for the maximum reach distance, when subjects were standing on their healthy leg compared to when subjects were standing on their injured leg with or

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without bandage. These statistically significant differences with medium effect sizes were exclusively found for the anterior direction (Figure 4).

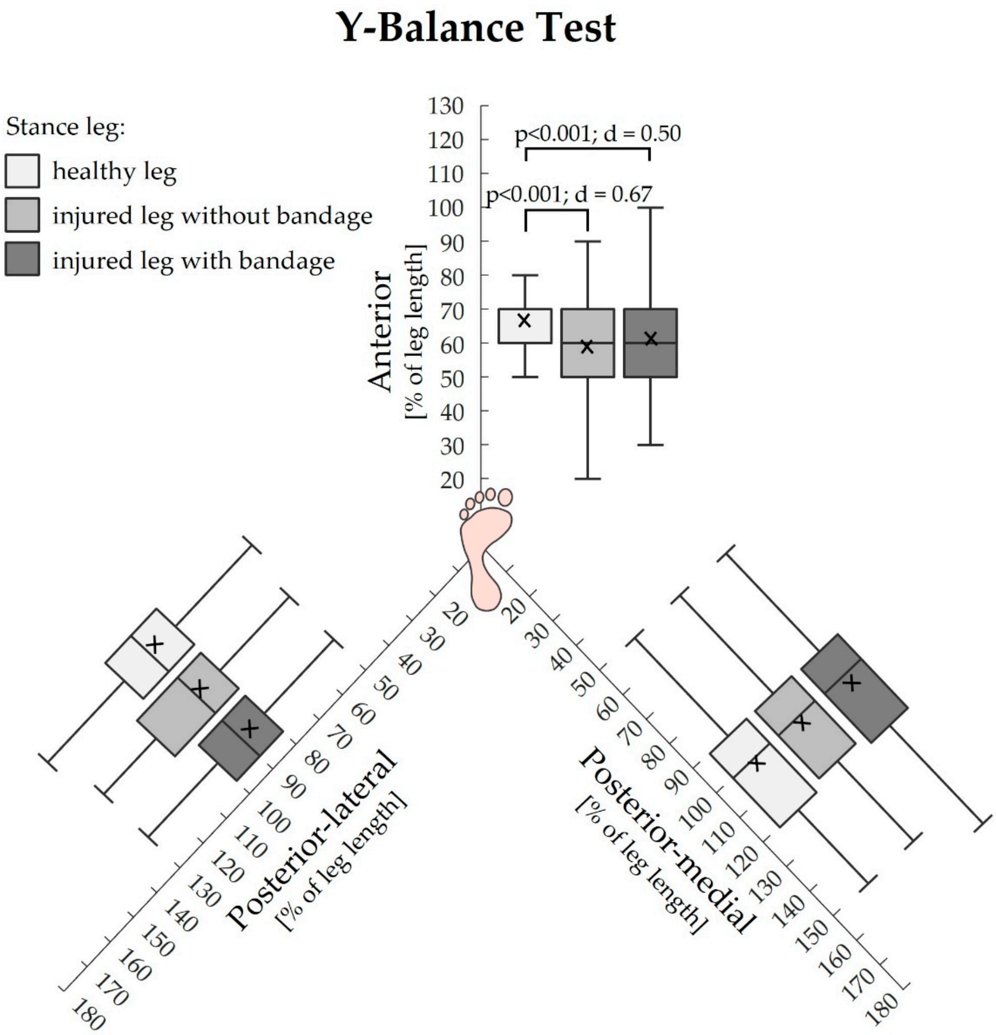

Figure 4. Comparisons of the three Y-Balance test directions between all three conditions healthy stance leg, injured stance leg without and with bandage. Data presented as percentage of the leg length. The cross additionally marks the mean value.

3.5. Gait:

As shown in Table 5, various statistically significant differences between the three walking conditions could be found. With respect to the healthy leg, the injured leg showed a shorter single stance phase and decreased second peak of the vertical force, regardless of wearing the bandage or not. The step length and the first peak of the vertical force did only reveal differences between the healthy and the injured leg without wearing the bandage. The step length for the healthy leg was decreased and the first peak of the vertical force was significantly higher.

When comparing walking with and without bandage, the healthy leg showed longer steps with higher vertical forces of the second peak when walking with bandage. The injured leg showed a longer relative single stance phase and higher vertical forces of the first and second peak, when walking with a bandage.

The parameters gait velocity and relative double stance phase, however, did not show any significant differences between the conditions walking with bandage and walking without bandage.

 doi:10.20944/preprints202405.2122.v1

Table 5. Intra-group and inter-group comparisons (between the healthy leg and the injured leg for the conditions walking with and without bandage) of the spatial-temporal and kinetic gait parameters. Data are presented as mean ± SD.

Parameter	Walking injured leg without bandage		Walking injured leg with bandage		p-value	d
gait velocity [km/h]	3.98 ± 0.67		4.01±0.59		0.251	-
rel. double stance phase [% of gait cycle]	29.17 ± 4.20		29.46 ± 4.22		0.121	-
Parameter	**healthy leg**	**Injured leg without bandage**	**healthy leg**	**Injured leg with bandage**	**p-value**	**d**
rel. single stance phase [% of gait cycle]	65.3 ± 2.7 a	64.1 ± 2.5 a;b	65.4 ± 3.2 c	64.7 ± 2.9 b;c	a < 0.001 b 0.018 c 0.013	a 0.46 b 0.22 c 0.24
step length [cm]	57.7 ± 6.1 a;b	61.1 ± 7.8 a	61.1 ± 8.5 b	61.0 ± 7.3	a < 0.001 b < 0.001	a 0.49 b 0.46
1. Peak of the vertical force [body weight]	1.07 ± 0.07 a	1.05 ± 0.06 a;b	1.07 ± 0.07	1.07 ± 0.07 b	a 0.004 b 0.004	a 0.31 b 0.31
2. Peak of the vertical force [body weight]	1.11 ± 0.07 a;b	1.08 ± 0.07 b;c	1.13 ± 0.06 a;d	1.11 ± 0.06 c;d	a 0.039 b < 0.001 c < 0.001 d 0.001	a 0.31 b 0.43 c 0.33 d 0.31

4. Discussion:

The aim of this study was to investigate the effects of wearing an ankle bandage on fine coordination and proprioception as well as on motor performance in subjects 5 weeks after orthotic treatment for acute ankle injuries. We hypothesized that wearing the bandage helps to reduce pain and improve fine coordination and proprioception. Moreover, it may also enhance motor performance, such as improving quasi static and dynamic balance performance, as well as normalizing gait.

4.1. Fine Coordination and Proprioception Test:

4.1.1. Effects of the Injury:

We found no statistically significant differences between any testing condition for the fine coordination and proprioception test. However, we observed a trend towards worse fine coordination for the healthy leg and the best fine coordination for the injured leg when wearing the bandage. These results were somewhat surprising since various other studies have shown impaired proprioceptive abilities as a consequence of damaged articular mechanoreceptors after spraining the ankle joint [3,13–18,29,51,52]. Therefore, we raised the question of what could have led to better performance of the injured ankle compared to the healthy ankle. Since those studies primarily investigated proprioception in CAI, rather than in the acute phase our results might possibly be attributed to increased awareness and caution when moving the injured leg. This notion is supported by the fact that our subjects still reported pain during the test [29,53,54]. Also, various compensation mechanisms could have played an important role. Since our patients were tested in an acute phase of the injury, the influence of active healing processes, such as increased blood flow and tissue supply, could have helped compensate possible injury-related proprioceptive impairments, resulting in slightly better performance [32,55]. There are also various types of mechanoreceptors found in different anatomical structures of the ankle joint, gathering afferent information to control movements. These receptors are situated within the ligaments, tendons, the joint capsule, surrounding muscles, and even the skin. Due to this redundancy, potentially unaffected structures might have compensated and reweighted the impaired function of those affected by the injury [56–58]. Since our test required subjects to move a pedal with inversion and eversion movements of the ankle joint to follow a presented target sine wave on the screen, the results of this test might also be dominated and possibly overcompensated by the visual system [20,56].

4.1.2. Effects of the Bandage:

A more plausible result of our study suggests that the injured leg with the bandage showed a trend towards better proprioceptive performance compared to without it. Although the literature yields inconsistent findings regarding the effects of bandages and elastic tapes on ankle joint fine coordination and proprioception, there may be several explanations for our results [26,59–63]. Since the bandage mechanically stabilizes the ankle joint, it increases resistance during joint movement. Consequently, it may have assisted and restricted the inversion and eversion movements of the ankle joint, especially at the reversal points of the pedal, which led to smaller error values during our test [33–35,64]. This gets supported by the results of the subjective data, where the subjects ranked the effects of wearing the bandage. The vast majority of the subjects reported from strong (50%) to moderate (48.6%) stabilizing effects of the ankle joint. For the fine coordination and proprioception test, 30% of the subjects reported strong improvements, while 50% still reported slight improvements when wearing the bandage. Another reason for enhanced proprioceptive performance using ankle supports, like bandages might have to do with the compression of the underlying musculoskeletal structures. Consequently, this might stimulate a greater number of cutaneous mechanoreceptors, as well as receptors of the joint capsule and ligaments, enhancing proprioceptive acuity and ankle movements [3,26,53,59,60]. Given that we only found a trend towards better proprioceptive performance and that hardly any other studies besides ours have investigated the effects of ankle support on proprioception in the acute phase rather than in CAI, the benefits of bandages on fine coordination and proprioception still appear elusive. One should also consider that our testing setup differed from that of other studies, which used detection of passive motion or active joint position tests. Therefore, comparing our results to those of other studies should be done carefully.

4.2. Motor Performance:

4.2.1. Effects of the Injury:

In terms of motor performance, the injured leg showed significant impairments compared to the healthy leg. This was demonstrated by higher sway values for the single leg stances, reduced reach distance for the Y-Balance test and impaired gait performance with longer steps, shorter single stance phases and smaller vertical ground reaction forces.

Two main causes might help to explain those findings: mechanical ankle instability (MAI) and functional ankle instability (FAI). Although those terms have primarily been used to describe the development of CAI, they also apply to the acute phase of ankle injuries, which has been analyzed in our study. While MAI is associated with complaints of mechanical instability and laxity, as well as pain and swelling, FAI is more related to impaired functional muscle control due to compromised proprioceptive and sensory structures [29,48,65,66]. Although both causes interact and overlap each other, higher sway values during quasi-static balance tasks, such as single leg stances might predominantly be explained by MAI [29,55,67]. That makes sense, considering that our patients reported complaints of laxity and instability. Our results are in line with various other studies [17,29,68–70]. For example, Hertel et al. reported that during single leg stances postural sway length and velocity increased significantly on the injured leg as compared with the uninjured leg [68].

Pourkazemi et al., even stated that single leg stances most strongly discriminated between participants with ankle sprains and healthy control subjects [69]. These results may be due to changes in postural strategies. Maintaining balance is usually accomplished by using either the ankle strategy or the hip strategy. The ankle strategy shifts the center of gravity by moving the entire body as a single-segmented inverted pendulum around the ankle joint, whereas the hip strategy involves moving the body as a double-segmented inverted pendulum with counter-phase motions around both the hip and ankle joints [22,68,69,71]. As a result of the injury, the subjects may switch from the typical ankle strategy to the hip strategy, which is less effective for quasi-static balance tasks [69,72,73]. Nevertheless, there are also several studies, which contradict our study findings for the single leg stance test [32,74,75]. Possible explanations for this contradiction might include varying methodological factors, such as differences in test paradigms and study groups. Most of those studies investigated patients with CAI, however not patients in the acute phase of the injury. As suggested by Ross and Guskiewicz, quasi-static balance tests might have limited sensitivity, because they only assesses a single component of balance and therefore should be supplemented by additional, more challenging measures, like the Y-Balance test [69,75].

The Y-Balance test quantifies the ability to maintain a stable base of support while reaching as far as possible with the lower limbs. In our study, the maximum reach distance was significantly reduced when subjects were standing on their injured leg without a bandage compared to when they were standing on the healthy leg. However, we only found this for the anterior direction, but not for the posterior-medial or posterior-lateral directions. While the literature yields inconsistent results regarding the most impaired reaching direction, some studies have also reported impairments in the anterior direction [47,49,69,76]. For example, Pourkazemi et al. reported that a reduced anterior reach distance most strongly discriminated between subjects with ankle sprains and healthy subjects [69]. Similar results have also been found in the study by McCann et al., where the study group with CAI achieved lower anterior test scores compared to subjects coping with lateral ankle sprains [76]. Since the Y-Balance test is considered a measure of dynamic postural stability, patients' diminished reach distance might predominantly be related to FAI [69]. This might be true, as some studies have reported altered lower limb muscle activity in patients with CAI when performing anterior reaches [77,78]. In both studies they found less activity for the tibialis anterior and peroneus longus muscles compared to patients coping with CAI. Another key factor contributing to patients' impaired anterior reach distance could be altered kinematics resulting from reduced ROM of the ankle joint [44,45,69,79]. In the studies from Pourkazemi et al. and Basnett et al. subjects with CAI exhibited restricted dorsiflexion motion in comparison to healthy control groups. Patients' limited ROM moderately correlated with the anterior reach distance of the Y-Balance test [69,79]. It has also been reported that individuals with CAI showed reduced hip and knee flexion while executing the test in the anterior direction. Furthermore, knee flexion and torso rotation have been identified as the primary kinematic predictors of reach distance during performance in the anterior direction [45,76]. Hence, limited ankle dorsiflexion ROM is a strongly limiting factor for the Y-Balance test anterior performance [44,48,80]. However, other than in our study, various authors reported from significantly diminished reach distances not only for the anterior direction, but also for the posterior-lateral [44,46,47,49,78] and posterior-medial [46,81] directions among patients with CAI when compared to healthy subjects, CAI copers, or the injured and uninjured sides. Similar to the anterior direction, diminished reach distance in both posterior directions might include reduced activity of lower limb muscles [77,78,82], as well as altered kinematics due to restricted dorsiflexion ROM [44–47,76]. Other factors may include pain and fear of falling due to ankle instability. Although the results are controversial, proprioceptive and neuromuscular deficits might also play a role [29,44,47,53,57,59,68].

During walking, we found significant differences in spatial-temporal parameters for the injured leg compared to the healthy leg. In more detail, the injured leg showed longer steps and shorter single stance phases during walking. Since longer steps typically signify higher gait quality, our observation might seem confusing at the first glance. It even seems to contradict various other studies in which reduced step lengths were reported for patients with ankle injuries [54,83–85]. However, there is a simple methodological explanation for this contradiction. In the mentioned studies they conducted inter-individual investigations, comparing a group with ankle injuries to another group of healthy subjects. In contrast, we observed intra-individual effects of the ankle injury by comparing the injured leg with the healthy leg within the same subjects. As the healthy leg compensates for impairments of the injured leg, patients in our study attempted to extend the step length of the injured leg to increase swing time and consequently minimize the loading time of the injured leg. This gets supported by our findings of reduced single stance phases for the injured leg during walking [54,83–85]. Since our patients were tested in the acute phase of the injury, this effect is likely driven by the pain they reported, as well as by fear of falling [54,84]. Other spatial-temporal parameters reported in the literature to characterize impaired gait performance in patients with ankle sprains include reduced walking speed, decreased cadence, and wider steps [54,83–86]. Other studies also reported from a decrease in vertical foot-floor clearance before heel strike, an increased inversion velocity during heel strike, reduced maximum plantar flexion during the stance phase, and a more inverted foot position throughout the entire gait cycle [44,54,65,86–88]. The altered kinematics of the patients may help to explain the differences we found for the kinetic parameters comparing the injured and healthy legs. In more detail, we observed diminished ground reaction forces for the injured leg for the first peak, corresponding to the loading response, and the second peak, corresponding to the terminal stance phase of the gait cycle [50]. Accordingly, our results overlap with those of several other studies [54,89,90]. For example, Nyska et al. reported a reduced impact at the beginning and end of the stance phase with a significant reduction in the relative forces under the heel and toes in subjects with CAI during walking. The authors also reported slower weight transfer from the heel to toe, and a lateral shift of the foot's COP, probably caused by a more inverted foot position [90]. Similarly, in the studies by Punt et al. and Doherty et al., the authors observed decreased maximum power and reduced maximum moments in patients with ankle sprains compared to healthy individuals [54,89]. The findings of patients unloading their injured leg during walking contrast those of Koldenhoven et al., which found increased ankle plantarflexion moments during the late stance phase to toe-off [86]. Nevertheless, this may be due to differences in study methods. In their study, subjects walked on a split belt treadmill and wore standardized shoes, whereas in our study, patients were barefoot and walked across a pressure distribution platform. Furthermore, they tested patients with CAI, whereas our patients were in the acute phase of the injury and reported pain during walking. The impaired gait pattern from patients with ankle sprains is considered to have a multifactorial pathology and can be attributed to several co-existing factors. This includes mechanical instability, proprioceptive impairments, neuromuscular control deficits, postural instability, reduced ROM of the ankle joint, altered activation of lower limb muscles, as well as pain and fear [15,17,29,44,54,55,57,65,69,83,84,86–88,91–94].

4.2.2. Effects of the Bandage:

Wearing the bandage in the acute phase of the injury significantly enhanced our subjects' single leg stance performance and normalized gait. However, the bandage did not improve our subjects' reach distance for the Y-Balance test.

Our findings of reduced sway when wearing the bandage during single leg stances are supported by two studies from Hadadi et al. In those studies, the authors concluded that both the immediate use of soft or semi-rigid ankle braces and their continuous use for four weeks improved single leg stance performance in subjects with CAI [12,95]. Small but significant and effective benefits on single leg stances in patients with ankle injuries using soft or semi-rigid orthosis have also been found in the studies from Best et al. and Faraji et al. [3,32]. Moreover, in the study from Baier and Hopf, the authors found that in athletes with functional ankle instability, a flexible ankle orthosis significantly reduced the medio-lateral sway velocity during single leg stances and changed the sway pattern by reducing the percentage of linear movements [96]. The positive effects of ankle support on quasi-static balance tasks, such as single leg stances, may predominantly be explained by proprioceptive stimulation, and by mechanical support. By stimulating cutaneous mechanoreceptors and exerting pressure on underlying musculoskeletal structures, ankle supports might offer additional sensory input about joint position and movements. Therefore, ankle supports may help detecting internal balance perturbations, thereby improving the control of postural sway in individuals with ankle sprains. [3,12,96,97]. The observation that the decrease in postural sway due to wearing ankle supports is more pronounced in patients than in healthy subjects reinforces this theory [96–98]. Apart from proprioception, a noticeable portion of the improvements could be attributed to mechanical stabilization [12,53,96,99]. This gets supported, by the study from Thonnard et al., in which they investigated the inversion torque of bare and braced ankles under static and dynamic conditions using a customized mechanical apparatus. In their study they found that the additional inversion ankle torque generated by an elastic brace effectively increased the passive resistance against ankle inversion movement compared with the bare ankle tests. Although the additional torque provided by the braces was small relative to the torques and forces applied to the foot during a typical sprain situation, it might contribute to additional stability during single leg stances, resulting in reduced sway [34,64]. That also aligns with findings that ankle-injured subjects report feeling more stable and comfortable during balance testing when wearing orthotics [97,99]. Also, in our study, the vast majority of subjects reported strong (50%) to moderate (48.6%) stabilizing effects on the ankle joint when wearing the bandage. For the single leg stance test, 27.1% of the subjects reported strong improvements, while 40.0% still reported slight improvements when wearing the bandage. Furthermore, reduced pain perception when wearing the bandage might have had a positive effect on postural sway.

In our assessment of dynamic postural stability using the Y-Balance test, we did not observe any improvements in patients' reach distances while wearing the bandage, regardless of the testing direction. This seems surprising, since wearing the bandage enhanced single leg stance performance and gait in our study. However, there might be some explanations. In the study from Alawna et al. they investigated the effects of ankle taping and bandages on the reach distance of one-hundred patients with CAI. They conducted measurements at baseline, immediately after support, and then at 2 weeks and 2 months post-support. Their results showed that ankle taping and bandaging does not immediately improve reach distance, however after 2 weeks and 2 months [59]. Moreover, in the study by Hadidi et al., they investigated the effects of ankle taping and soft or semirigid ankle braces on the reach distance of the Y-Balance test before and after a 4-week intervention period. Their findings showed that the use of tape and a soft or a semirigid ankle brace for 4 weeks were all beneficial in improving the reach distance in individuals with CAI [51]. Also, in the study from John et al., they investigated the effects of an elastic ankle support on dynamic balance in patients with CAI using the Y-Balance Test. The authors concluded that the acute use of elastic ankle support was ineffective in enhancing dynamic balance [100]. Considering those as well as our results, it seems that patients may need some time to adapt to the bandage in order to fully experience its positive effects on mechanically stabilizing the ankle joint and enhancing proprioception for this specific test. This might be true, as the Y-balance test is particularly challenging and differs from more daily activities, such as standing on one leg or walking. Because we tested patients in the acute phase, their pain and fear of falling might have been more severe compared to studies involving patients with CAI, further potentially limiting the effectiveness of the bandage condition in our study.

Regarding gait, we were surprised to find only one study investigating the influence of orthotic support in patients with ankle injuries [85]. In this study, 10 subjects with CAI walked without a brace, with a flexible brace, and with a semi-rigid ankle brace while their kinematics and kinetics were recorded using a marker-based system and a force plate. Although the effects were small, few differences were noted between the brace and no brace conditions. In summary, the authors described the effect of wearing braces during walking, noting altered foot angles at the heel strike and toe-off, altered braking forces, reduced step lengths, and a reduction in the stance phase. Therefore, this study partly confirms our findings, of extended stance phases and higher vertical ground reaction forces for the loading response and the terminal stance phase when walking with the bandage compared to walking without the bandage. Noteworthy, wearing the bandage during walking also improved our subjects' healthy leg performance, resulting in longer steps and higher vertical ground reaction forces during the terminal stance phase. Consequently, wearing the bandage might aid in reducing asymmetry, which could potentially mitigate the risk of injuries [101,102]. The proposed mechanisms explaining the effectiveness of ankle orthoses during walking might include mechanical support, improving proprioceptive and sensorimotor function, as well as enhancing ankle positioning and muscular efficiency around the ankle joint [12,53,64,99,103]. Spaulding et al., suggested that ankle braces affect forward progression without significantly impacting gait characteristics or causing compensatory or adaptive motion elsewhere in the lower limb [85]. Specifically, the reduction of pain when wearing the bandage might have encouraged our patients to exert more and longer-lasting loads on the injured leg during the single stance phase of the gait.

Interpreting our results should be done in light of some restrictions. First, comparability to other studies might predominantly be restricted to those studies which methodologically come close to our study design. Since a wide variety of ankle supports has been investigated in the literature, studies that utilized soft ankle supports may be most comparable to the ankle bandages we used in our study. In this regard, it should also be noted that while most other studies investigated the effects of ankle support in patients suffering from CAI, we focused on patients in the acute phase of ankle injuries. Specific limitations of our study include the inability to identify the exact ankle injury due to the absence of Magnetic Resonance Imaging (MRI) investigations. Further studies should include kinematic analysis of the subjects' motion, as well as analyzing leg muscle activity using electromyographic sensors. It also would be interesting to compare the efficacy of different ankle supports, as our study focused solely on ankle bandages.

5. Conclusion:

Five weeks after the ankle injury, subjects reported mild to moderate pain and ankle instability, and showed impaired motor performance in the injured leg compared to the healthy leg when not wearing the bandage. This included higher sway values for single leg stances, reduced reach distance in the Y-Balance test, and impaired gait performance characterized by longer steps, shorter stance phases, and smaller vertical ground reaction forces. No impairments were found in the fine coordination and proprioception tests. Subjects reported moderate to strong improvements in ankle stability and pain when wearing the bandage. Wearing the bandage significantly normalized subjects' single leg stance performance, as well as the single stance phase duration, and the vertical ground reaction force during walking. However, the bandage did not have a clear effect on fine coordination and proprioception. Therefore, we conclude that wearing a bandage in the acute phase of an ankle sprain may immediately improve motor performance, including standing and walking.

Author Contributions: Conceptualization, A.K., T.L.M.; methodology, A.K., T.L.M.; software, T.H., C.M.; validation, T.H., C.M; formal analysis, T.H., C.M.; investigation, A.K.; resources, A.K.; T.H., C.M., T.L.M.; data curation, C.M., T.H., T.L.M; writing—original draft preparation, T.H., C.M., A.K.; writing—review and editing, T.H., C.M., A.K., T.L.M.; visualization, T.H., C.M.; supervision, C.M., T.L.M., A.K.; project administration, T.H., C.M., A.K.; funding acquisition, T.H, C.M. All authors have read and agreed to the published version of the manuscript.

Funding: Bauerfeind AG provided financial and material support for this study. The publication of this article was funded by Chemnitz University of Technology and by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) project number 491193532.

Institutional Review Board Statement: All procedures were conducted according to the recommendations of the Declaration of Helsinki and were approved by the Ethics Committee of the Faculty of Behavioural and Social Sciences of Chemnitz University of Technology (V-320-17-LN-MalleoTrain-07042019).

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

Data Availability Statement: The dataset used and analyzed in this study is available from the corresponding author upon reasonable request.

Acknowledgments: The authors would like to thank all subjects and Bauerfeind AG for supporting this study. We would also like to extend special thanks to Laura Niklaus for data acquisition, and to Ralph Dörfler and Philip Schulze for providing technical support.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in writing the manuscript, or in the decision to publish the results.

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