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„Temporal and kinematic variability in backward walking on a treadmill"

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Abstract

The familiarisation time while moving on treadmills to gain stable kinematic and temporal data is of great importance. Not considering the habituation process may lead to problematic results (Matsas et al., 2000). To the best of our knowledge for backward walking no study with the goal to determine familiarisation time on treadmills has yet been conducted. Therefore, this study chose to tackle this problem and determine the time needed to get familiarised with walking backward on a treadmill. The parameters investigated were hip, knee and ankle kinematics and temporal gait measurements. These parameters were assessed at certain discrete gait events like touch-down, take-off and when maxima and minima values occurred. Additionally, the whole motion of the ankle, knee and hip throughout the stance phase beginning at touch-down and ending at take-off was analysed with the Procrustes Analysis. After a 5 minute backward warm-up participants had to walk 12 minutes at two different walking speeds as walking speed has an impact on kinematic measurements (Stoquart et al., 2008). One was determined by the authors of the study prior to testing (2.5km/h) and the other was the individually self-selected comfortable walking speed (2.69±0.37km/h)

25 healthy subjects participated in the study of which 20 data sets could be used for further analysis. Among the population were 12 male and 8 female subjects. (age 24.9±3.5 years, height 1.76±0.07cm, mass 69.6±10.6kg). To gain kinematic and temporal data a Vicon Nexus V.2.8 Oxford Metrics system consisting of 12 Vicon Vantage cameras operating at 120Hz was used. Additionally, subjects had to wear pedar®-x insoles to determine the different gait phases.

98 of the 102 investigated kinematic and temporal parameters did not show any form of familiarisation. Only The contact times of the female population at fixed walking speed, the Procrustes distances of the hip angle at fixed walking speed, the knee angle at touch-down of the male population at voluntary walking speed and the Procrustes distances of the knee angle at voluntary walking speed of the whole population described forms of familiarisation. Therefore, we conclude that for 98 of the 102 investigated parameters 5 minutes of familiarisation time is needed to produce stable spatio-temporal data. For the other 4 previously described parameters at least 10 minutes of familiarisation time is needed.

Zusammenfassung

Die Zeit, die der Prozess der Gewöhnung an das Bewegen auf einem Laufband benötigt, um stabile kinematische und temporale Parameter zu erhalten, ist von großer Wichtigkeit. Die nicht Berücksichtigung einer Gewöhnungsphase kann zu verfälschten Ergebnissen führen (Matsas et al., 2000). Nach unserem besten Wissen ist uns keine Studie bekannt, die sich mit der Gewöhnung an das Rückwärtsgehen auf einem Laufband beschäftigt. Daher hat sich diese Studie das Ziel gesetzt der Frage nachzugehen, wie lang dieser Gewöhnungsprozess dauert, um stabile kinematische und temporale Parameter beim Rückwärtsgehen auf einem Laufband zu erhalten.

Die untersuchten Parameter waren Hüft-, Knie- und Sprunggelenkswinkel und Analyse des Gangzyklusses. Diese Parameter wurden zu diskreten Zeitpunkten des Gangzyklusses gemessen, wie zum Beispiel bei initialem Bodenkontakt, Schwungphasenvorbereitung und wenn Maxima und Minima der Winkel auftreten. Um die gesamte Bewegung der Hüft-, Knie- und Sprunggelenkswinkel während der Standbeinphase zu analysieren, wurde die Procrustes Analyse verwendet. Studienteilnehmer mussten 12 Minuten lang mit zwei unterschiedlichen Gehgeschwindigkeiten auf dem Laufband rückwärtsgehen, da die Gehgeschwindigkeit einen Einfluss auf kinematische Messungen hat. (Stoquart et al., 2008). Eine Gehgeschwindigkeit (2.5km/h) wurde von den Autoren dieser Studie im Vorhinein bestimmt und festgelegt. Die zweite wurde von den Teilnehmern bestimmt und ist die individuelle angenehme Gehgeschwindigkeit (2.69±0.37km/h).

25 gesunde Personen nahmen an der Studie teil, wovon 20 Datensätze für die weitere Analyse verwendet wurden. Von diesen 20 Teilnehmern waren 12 männlich und 8 weiblich (Alter 24.9±3.5 Jahre, Größe 1.76±0.07cm, Masse 69.6±10.6kg). Um kinematische und temporale Daten zu ermitteln, wurde das Vicon Nexus V.2.8 Oxford Metrics System bestehend aus 12 Vicon Vantage Kameras, die mit einer Frequenz von 120Hz aufzeichnen, verwendet. Zusätzlich wurden pedar®-x Sohlen verwendet, um die verschiedenen Phasen des Gangzyklusses zu ermitteln.

98 der 102 untersuchten kinematischen und temporalen Parameter zeigten keine Form der Gewöhnung. Nur bei den Kontaktzeiten der weiblichen Population bei 2.5km/h, den Procrustes Distanzen des Hüftwinkels bei 2.5km/h, dem Kniewinkel der männlichen Population bei initialem Bodenkontakt bei selbstgewählter angenehmer Gehgeschwindigkeit und den Procrustes Distanzen des Kniewinkels, ebenfalls bei selbstgewählter angenehmer Gehgeschwindigkeit, konnten Anpassungsprozesse über die 12 Minuten festgestellt werden. Aus den Ergebnissen geht hervor, dass für 98 der 102 untersuchten Parameter eine

Gewöhnungsphase von 5 Minuten auf dem Laufband ausreicht, um stabile spatio-temporale Parameter messen zu können. Für die zuvor genannten 4 Parameter sind zumindest 10 Minuten Gewöhnungszeit auf dem Laufband notwendig.

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1. Introduction

1.1. Forward motion

Saunders, Inman, & Eberhart (1953) describe human locomotion as “phenomenon of the most extraordinary complexity” (Saunders, Inman, & Eberhart, 1953, p. 543). The most common forms of locomotion used by human beings are walking and running. Walking enables human beings to move for a long period of time at slow speeds and running enables faster movement for a shorter period of time compared to walking. The gait for both forms of locomotion is almost similar and both can be divided in stance and swing phase. Considering the duration of these phases the two forms of locomotion differ considerably. The duration of the stance phase is longer in walking than in running while the swing phase is longer in running compared with walking. Additionally while walking there is always one foot in contact with the ground where in running there are times where both feet are in the air (Saibene & Minetti, 2003).

1.2. Treadmill and ground locomotion

The goal to move the body from point “a” to point “b” by either running or walking seems very simple but the analysis of such movement requires a big amount of data. To achieve a complete representation of human locomotion kinematic and kinetic analysis is required (Saunders et al. 1953). This analysis can either be done by walking on a treadmill or on ground and both methods have advantages and disadvantages. Walking on ground may seem more natural but for kinematic data only a small number of steps can be recorded per trial. Therefore, a big amount of trials is required to record a sufficient number of steps to gain reproducible data. Additionally, the walking speed may vary over the many trials (Stoquart, Detrembleur & Lejeune 2008). Treadmills on the other hand enable walking and running on a levelled or sloped surface at different speeds. It is a suitable device to create external conditions and one can gain high internal validity of the experimental process (Arsenault, Winter & Marteniuk, 1986). It also enables measurements of consecutive strides while using less space and additional ground reaction forces can be measured with certain instrumental treadmills (Sloot, van der Krogt & Harlaa, 2014). A question that arises when treadmill devices are implemented is the determination of the belt speed that should be used for the measurement. Often the analysis of gait is conducted while subjects walk at their preferred walking or running speed. This is due to the problem of imposing a speed on subjects who walk on ground. The problem what speed shall be used is also of big importance as kinematic, kinetic, electromyographic and energetic data vary depending on walking / running speed (Stoquart et al., 2008).

Another important issue is if human locomotion on a treadmill is comparable with human locomotion on ground. There are numerous studies that investigated the comparability of forward locomotion on a treadmill and on ground. For instance Nelson, Dillman, Lagasse, & Bickett, (1972), Riley et al, (2008) Sinclair et al., (2013) Baur, Hirschmueller, Mueller, Gollhofer, & Mayer, (2007) Barton, Kappel, Ahrendt, Simonsen, & Rathleff, (2015), Schieb, (1986) and Cronin & Finni, (2013) compared running on a treadmill to running on ground.

Other researchers conducted studies in order to compare various biomechanical characteristics of walking on a treadmill to walking on the ground (Alton, Baldey, Caplan, & Morrissey, (1998); Arsenault et al., (1986); Barton et al., (2015); Chockalingam, Chatterley, Healy, Greenhalgh, & Branthwaite, (2012); Cronin & Finni, (2013); Hollman et al., (2016); Lim & Lee, (2018); Matsas, Taylor, & McBurney, (2000); Murray, Spurr, Sepic, Gardner, & Mollinger, (1985); Riley, Paolini, Della Croce, Paylo, & Kerrigan, (2007); Watt et al., (2010). For example studies analysed the muscle activity via electromyography (Arsenault et al., 1986; Lim & Lee, 2018; Murray et al., 1985) while one (Lim & Lee, 2018) could find differences in muscle activity when walking on a treadmill compared to walking on ground. In the same study Lim & Lee (2018) also studied the pelvic movement while walking on a treadmill and on ground and concluded that the pelvic movement is not the same in both cases. These findings were supported by the study of Chockalingam et al., (2012) who also found differences in pelvic movement when comparing walking on ground and on a treadmill.

Considering kinematic comparison between forward walking on a treadmill and on ground no differences could be found when investigating knee kinematics and spatio-temporal parameters as cadence stride time and stride length (Matsas et al., 2000). Murray et al. (1985) came to the same conclusion by analysing the rotation of shoulder, elbow, pelvis, hip, knee, and ankle in the sagittal plane. Furthermore these results are supported by studies conducted by Riley et al. (2007) and Watt et al. (2010) who both investigated the hip, knee, ankle and pelvis. From the aforementioned studies only Watt et al. (2010) could identify certain spatio-temporal differences in the cadence, stride length and stride time. On the other hand Alton et al. (1998) and Hollman et al. (2016) came in their studies to the result that there are kinematic differences when walking on a treadmill compared to on ground. Alton et al. (1998) found differences when investigating stance time, cadence and the angle of the hip joint and Hollman et al. (2016) determined the long term variability for the parameters stride length, stride time, cadence, stride velocity, stance percent, sagittal trunk velocity and frontal trunk velocity as significantly different between walking on ground and on a treadmill.

1.3. Backward motion

The two most common forms of locomotion walking and running can also be used for backward movements. Backward walking has been the subject of numerous studies in the last years. For example, (Wang Yuan & An, 2018) in his meta-analysis attributes backward walking training to have a positive effect on spatial-temporal gait characteristics in forward walking. Examining the effect of backward locomotion on health Rose, DeMark, Fox, Clark, & Wludyka, (2018) and Yang, Yen, Wang, Yen, & Lieu, (2005) both concluded in their studies that backward walking training could improve forward walking speed in patients who recently suffered from a stroke. In another study Kachanathu, Hafez, & Zakaria, (2013) found out that backward walking could lead to an improvement in lower extremity strength and static balance. The authors further pointed out that especially the quadriceps and ankle plantar flexor muscles strength could be improved by backward walking.

Besides researching the effect of backward walking on a levelled surface also the effects of backward walking down a slope has been researched. One point of interest was the effect of backward locomotion on a sloped surface on the lower extremities. Hösl et al. (2018) compared the effects of backward downhill training on a treadmill to the effects of static plantar flexor stretching on the mobility of the ankle joint, walking function and muscle-tendon morphometrics. Joseph et al. (2016) researched the effect of backward downhill treadmill training on the Achilles tendon and Nottle & Nosaka, (2005) investigated the muscle damage that occurs through such a training intervention. Other studies focused on the effect on heart rate and oxygen consumption (Hooper et al., 2004) and the overall therapeutic effects of downhill backward walking (Cha et al., 2016).

Backward locomotion is either studied via trials on ground (Soda et al., 2013; D. Winter et al., 1989) or on treadmills (Cha et al., 2016; Fritz et al., 2013; Corey W. Joseph et al., 2014; Suenaga et al., 2013; Terblanche et al., 2003). Without treadmills kinematic and kinetic analysis of backward walking can be realised along a walkway. For that purpose, a motion capture system and retro-reflective markers are used to capture kinematic data of backward walking trials. Additionally, force plates placed on the walkway can capture the developed ground reaction forces (Lee et al., 2013; Soda et al., 2013). To ensure a constant walking speed during multiple trials, the cadence of the self-selected walking speed can be mimicked by means of a metronome (D. Winter et al., 1989).

Similarities between forward and backward walking were investigated by Winter et al. (1989). Results showed that the movement pattern of the hip joint and the knee joint were very similar when backward motion was time-reversed. Only the movement of the ankle joint showed big differences. Additionally; the backward walking trials showed a bigger variability of the joint moment patterns of hip, knee and ankle compared to forward walking. The authors further speculated that the participants unfamiliarity to the backward motion could be the reason for the increased variability (D. Winter et al., 1989).

For the investigation of human adjustments to walking or running during treadmill sessions 3 different terms (familiarisation, habituation and accommodation) are used. Although the words familiarisation and habituation are defined differently according to the oxford dictionary, in research they are used interchangeably describing the same process. *Familiarisation* describes the process of stabilisation of kinematic and spatio-temporal parameters to a point where no significant differences can be determined by repeated measurements (Arnold et al., 2019; Matsas et al., 2000). The term *habituation* defines the constancy of stride, the stability of pattern (Wall & Charteris, 1981) or constancy of gait (Charteris & Taves, 1978) and therefore leads to the conclusion that the two different terms are used for the same process. Whereas Charteris & Taves, (1978) limit their definition of *habituation* not only to one session but also to subsequent sessions on different days. Furthermore, in the literature there is a differentiation between *habituation* and *accommodation*. For example the latter term describes the rapid initial adaptations to moving on a treadmill in the first few steps (Wall & Charteris, 1981). Additionally, accommodation is described as adjusting to “the new modality, a faltering balance-regaining “tripping” in the first steps taken” (Charteris & Taves, 1978, p. 664).

Nonetheless, when investigating a form of locomotion on the treadmill it is important that the subjects are familiarised with the treadmill before starting measurements. Failing to include familiarisation into a study that includes a treadmill is considered a major limitation of a study (Matsas et al., 2000). For forward walking on a treadmill several studies investigated the duration a subject needed in order to get familiarised on the walking device (Matsas et al., 2000; Meyer et al., 2019; Taylor et al., 1996; Van de Putte et al., 2006; Wass et al., 2005; Zeni & Higginson, 2010).

To obtain kinematic data the subjects are recorded with a 2D or 3D motion capturing system while walking on the treadmill. For that purpose, important anatomical landmarks as ankle, knee joint, hip joint were marked with reflective markers (Matsas et al., 2000; Meyer et al., 2019; Wass et al., 2005; Zeni & Higginson, 2010). Another method is to videotape the subjects with a camera setup consisting of two cameras and analyse the video footage with a 3D analysing tool (Taylor et al., 1996).

1.4. Determination of the walking speed

Another important issue in the kinematic measurement is the determination of the subject’s speed. For that reason, subjects often walk on a treadmill with their comfortable walking speed.

To determine the individual comfortable speed subjects often walk multiple times on the ground. For example, in the studies of Matsas et al (2000) and Wass et al. (2005) participants had to walk 6 times across a 10-meter walkway at their self-selected speed. A camera focused on the middle 6 meters obtained knee kinematics and other spatio-temporal gait measurements. The average walking speed of 6 trials was calculated for each subject and used as the speed on the treadmill. This resulted in an average walking speed of 5.0±0.5 km/h and 4.0± 0.81 km/h in the two studies (Matsas et al., 2000; Wass et al., 2005). A different approach is to let the subjects walk at 50% of their maximum walking speed (Meyer et al., 2019). For that reason the authors determined the maximum walking speed while subjects walked over a 25-foot walking lane twice and the average speed of the two trials was calculated (Meyer et al., 2019). An alternative approach for the determination of the individual walking speed is to consider the individual limb length to determine the walking speed. For this purpose, the Froude number was used which is described in the formula below.

$$F = \frac{v}{g * L}^{2}$$

$$F = Froude\ number, v = walking\ speed, g = gravity, L = leg\ length$$

Research showed that at optimal forward walking speed, which corresponds to a Froude number of ~0.25, the energy recovery due to the pendulum mechanism reaches maximal values and the metabolic cost of locomotion is reduced to its minimum (Saibene & Minetti, 2003).

In a previous experiment (Van de Putte et al., 2006) determined the Froude number of 0.142 by previously letting the 10 study participants walk at their natural self-selected walking speed. This led to an average walking speed between 1.1-1.2 m/s or 3.96-3.32 km/h (Van de Putte et al., 2006). Another study investigating the pelvic and spinal movement during walking chose to divide the participants into two groups with different walking speeds. One group had to walk at their preferred walking speed and the other at 60% of their preferred walking speed. To determine the preferred walking speed a Clynical Stride Analyser (B & L Engineering, Sante Fe Springs, CA, USA) was used (Taylor et al., 1996).

In the literature we can find different methods for the determination of the preferred walking speed. For example, two studies determined the preferred walking speed through walking on a treadmill. In the first study (Mannering et al., 2017) the subjects started at a slow speed and the speed increased in certain intervals until the subject confirmed that the current speed felt comfortable. In the other study Oudenhoven et al. (2019) additionally added a second step to this procedure. After increasing the speed until the subject felt comfortable, they accelerated the treadmill until the subject had to start running and decreased the speed afterwards until the subject confirmed that the speed felt comfortable for walking again.

Beyond the determination of the walking speed, another important issue is the duration of the walking task as well as the segmentation process of the whole movement. According to literature we find walking durations from at least 10 minutes and up to 45 minutes on a treadmill (Matsas et al., 2000; Meyer et al., 2019; Taylor et al., 1996; Van de Putte et al., 2006; Wass et al., 2005). While walking measurements are made in regular intervals in different studies the interval durations are varying from one minute (Zeni & Higginson, 2010), two minutes (Matsas et al., 2000; Taylor et al., 1996; Wass et al., 2005) and five minutes (Van de Putte et al., 2006). Also a continuous kinematic recording (Meyer et al., 2019) was chosen throughout a 10 minute walking period. In this particular study, the recorded footage was divided subsequently into batches of 25 steps of which the mean values were calculated for later comparison.

1.5. Determination of gait events

In order to compare selective kinematic and dynamic parameters through different gait cycles the human motion must be segmented in distinct gait events. The segmentation process can include one or multiple stance or stride times. Stride is mostly defined as a consecutive touch-down of the ipsilateral limb. For that purpose, different kinematical or dynamical methods can be implemented (Matsas et al., 2000; Van de Putte et al., 2006). For example, Matsas et al. (2000) identified the different gait cycle events of walking by means of sensitive pressure insoles. Another method to determine the different events of the gait cycle is to use an instrumental treadmill that has integrated force plates (Van de Putte et al., 2006). With that method the vertical forces can act as a detection instrument of the gait cycle. The different phases of the walking gait cycle can also be determined through analysis of the kinematic data gained through the recordings (Wass et al., 2005; Zeni et al., 2008; Zeni & Higginson, 2010). In the study of Stolze et al. (1997) the gait cycles were determined by analysis of the video footage frame by frame.

1.6. Dependent variables

Through the segmentation the comparison of variables of interest (kinematic, dynamic, or electromyographic) can be performed. Most studies compared the variables at certain discrete moments of time: for instance at touch-down, take-off, midstance and in cases where maxima or minima values occurred (Matsas et al., 2000; Van de Putte et al., 2006; Wass et al., 2005).

1.7. Familiarisation

In order to make biomechanical comparisons between ground and treadmill motions it must be verified that the humans are not influenced by the new and uncommon device (treadmill). Therefore, a familiarisation time is needed for the subject to adapt to the new motion task. The familiarisation time needed varies, depending on the investigated parameters and the participating subjects. For example the study of Wass and colleagues showed that elderly people did not exhibit any form of familiarisation after walking 15 minutes on a treadmill (Wass et al., 2005). In another study when considering knee kinematics in young unimpaired subjects, four minutes of familiarisation time was necessary. Additionally, in the same study the spatio-temporal parameters (cadence, stride time and step length) were stable after six minutes (Matsas et al., 2000).

In a recent study Arnold, Weeks, & Horan, (2019) came to a similar conclusion where they investigated the habituation to treadmill walking with shoes and in barefoot condition. In both cases the spatio-temporal variables (stride length, cadence) were stable after six minutes and after eight minutes the kinematic variables (hip, knee and ankle angles) were stable as well. In another study (Van de Putte et al., 2006) knee kinematics and spatio-temporal data were stable immediately after the treadmill had reached its defined speed (in about 30 seconds). Only the stride length needed 10 minutes to become stable and reproducible (Van de Putte et al., 2006). Similar to the findings of Matsas et al. (2000) another recent study (Meyer et al., 2019) investigated 26 kinematic and spatio-temporal parameters and determined the time a young and elderly population needed for familiarisation to treadmill walking to six minutes.

Also Zeni & Higginson, (2010) came to the conclusion when analysing the ground reaction forces, knee kinematics and spatio-temporal parameters that 5 minutes are needed to be familiarised when walking on a treadmill. On the other hand Taylor et al. (1996) examined the pelvic and spinal movement on the treadmill during walking and found out that four minutes of familiarisation time was needed in order to produce stable kinematics (Taylor et al., 1996).

While the investigation process of different parameters during treadmill walking is quite similar between different studies, the definition of familiarisation varies. For example Matsas et al. (2000) considered their subjects to be familiarised when “ICC values became maximal, when no significant differences between the dependent variables at different treadmill walking times were found, and when mean absolute difference scores were minimal from one treadmill walking time to the next” (Matsas et al., 2000, p. 50).

This method can be found also in the study of Wass et al. (2005) who investigated the familiarisation of elderly people while walking on a treadmill. In another approach Meyer et al.

(2019) investigated kinematic and spatio-temporal parameters and they determined the familiarisation differently. They defined four different states of acclimatisation beforehand:

> (1) Acclimatization with plateau: ≥4 consecutive bins must be statistically significantly different from the first bin in post-hoc tests for plateau onset to be defined. The plateau is maintained if no subsequent bin is significantly different from the initial bin of the plateau (if this requirement is not met, plateau onset is moved to a later bin until criteria are met), and no run of ≥4 bins is no longer significantly different from the first bin.
>
> (2) Steady acclimatization without plateau: Plateau onset as defined in 1 but subsequent bins after plateau onset are significantly different from the initial bin of the plateau.
>
> (3) Acclimatization with interim plateau: a plateau as defined in (1) ends if ≥4 further consecutive bins were no longer significantly different from the first bin. No further plateaus meeting criteria (1) are reached.
>
> (4) No acclimatization: none of the above criteria apply.
>
> (Meyer et al., 2019, p. 3)

1.8. Procrustes Analysis

Through examination of the time series, various biomechanical parameters are generated and comparisons are performed by a very small number of discrete parameters Nüesch et al. (2019) such as: peak values, the start or end of the motion, average values, range of motion, etc., assuming that those biomechanical parameters have a functional relevance. Nonetheless, those discrete biomechanical parameters cannot represent important aspects of the time series such as the shape of the curve path and therefore are limited in their capacity to detect meaningful differences between conditions or populations. (Nüesch et al., 2019) In order to circumvent that limitation other methods such as “Procrustes Analysis” or “Statistical Parametric Mapping” which examine the complete time series, have been developed. A short description of the Procrustes Analysis will be presented in the following paragraphs.

The name Procrustes Analysis derives from Greek mythology. A giant named Procrustes tormented his victims by fitting them into an iron bed. If their body was shorter than the bed, he lengthened their body and if it was longer, he shortened their body. The outcome of this procedure was the death of his victim (Crosilla et al., 2019).

The Procrustes Analysis or Procrustes Technique is a combination of mathematical procedures which transform comparable points to align them to their maximum agreement. Its origin is awarded either to the psychometrist Osier or the morphometrists Boas and Phelps. Since the 1950s this method has been continuously researched and improved. Nowadays this method is widely used in different scientific fields and applications like "in statistics, in multifactorial analysis, in management engineering, in biometrics, for the recognition and classification of genes and of the molecular components, especially with medical aims, as well as in the typical computer applications like image matching and robotic vision" (Crosilla et al., 2019, p. 8).

The General Procrustes Analysis is a method which compares shapes with each other (Ross, 2004). Shape is defined as "all the geometrical information that remains when location, scale and rotational effects are filtered out from an object" (Stegmann & Gomez, 2002 p. 2). Due to this definition one can rotate, translate and perform isomorphic scaling on shapes without changing the shape itself (Ross, 2004). The General Procrustes Analysis compares any number of shapes to a target shape, for instance the mean of a set of shapes.

Decker, Berge, Renous, & Penin (2007) used the Procrustes Analysis in their study "An alternative approach to normalization and evaluation for gait patterns: Procrustes analysis applied to the cyclograms of sprinters and middle-distance runners" to analyse the gait of middle-distance runners and sprinters. They created the mean shapes of the ankle and knee cyclograms for both groups and compared the cyclograms of runners and sprinters with each other (Decker et al., 2007).

In this paper the Procrustes Analysis will be used in a similar way to the study conducted by Decker et al. (2007). But instead of comparing the different gait characteristics with an ideal or mean gait, measurements made at different moments will be compared to each other using the Procrustes Analysis.

1.9. Objective

To the best of our knowledge no study investigated the familiarisation time needed for backward walking on a treadmill yet. Therefore, in this study we will tackle that shortcoming by examining various kinematic and temporal biomechanical parameters by comparing either discrete or time series values over different instances.

1.10. Hypothesis

Based on the previous literature findings regarding the habituation time for forward walking on a treadmill (Matsas et al., 2000; Meyer et al., 2019; Taylor et al., 1996; Van de Putte et al., 2006; Wass et al., 2005; Zeni & Higginson, 2010) we formed our hypotheses:

H0: Backward walking will need less than 6 minutes of habituation to obtain stable kinematic and temporal biomechanical parameters.

H1: Backward walking will need more than 6 minutes of habituation to obtain stable kinematic and temporal biomechanical parameters.

2. Methods and Materials

2.1. Participants

Twenty-five subjects of which 15 were male and 10 were female participated in the study. Of these the data of 20 subjects including 12 males and 8 females (age 24.9±3.5 years, height 1.76±0.07m, mass 69.6±10.6kg) was used for further analysis. They were between 18 and 32 years old at the time of the examination. They were all active in various sporting activities and none of them had experience in backward walking. Written informed consent was obtained from all participants prior to the study. The Ethics Committee of the University of Vienna approved the conduction of the study. All the participants were healthy and without injuries when they were tested on the treadmill.

2.2. Kinematic

For the kinematic analysis the Vicon Nexus V.2.8 Oxford Metrics located at the Institute for Sports Science of the University of Vienna was used. The system consisting of 12 Vicon Vantage Cameras operating at 120Hz was used to capture seven reflective markers (Figure 1A and 1B). These were positioned on anatomical landmarks of the subjects: C7, right trochanter, right epicondyles medialis and lateralis, right malleolus medialis and lateralis, right calcaneus and right fifth metatarsal bone. The markers on the C7 and the right trochanter had a diameter of 19 mm and the others were of 14 mm diameter. With the markers at C7, trochanter and the middle point connecting both epicondyles defined the Hip joint angle (straight = 180°). The trochanter, epicondyles and malleoli markers defined the knee joint angle (straight leg = 180°) and the epicondyles –malleoli and calcaneus markers defined the ankle joint angle (tibia perpendicular to foot = 90°).

In figure 1C the model created with the Vicon nexus through marker tracking is depicted.

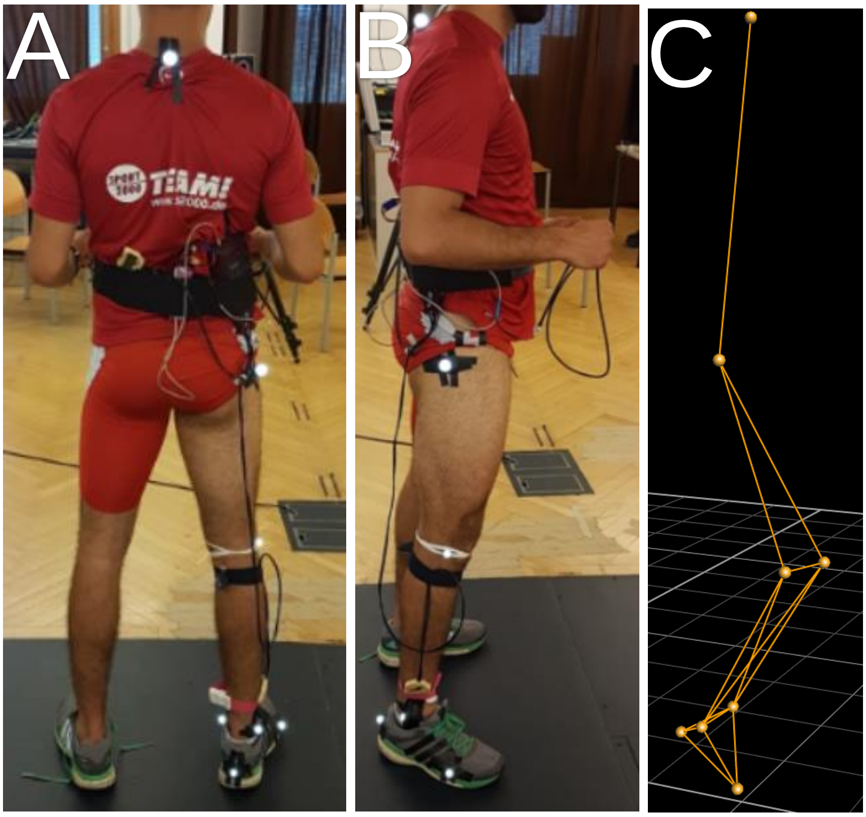

Figure 1: Depiction of the marker placement in the posterior view (A) the sagittal plane (B) and the simplified model (C).

2.3. Pedar

To determine gait events, we used the pressure sensitive insole of the pedar®-x system (novel GmbH, Munich, Germany). The pedar®-x insoles function on the principle of capacitance transducer which is described in the following paragraph.

> A capacitance transducer consists of 2 plates made of a conducting material separated by a nonconducting or insulating layer termed a dielectric. The transducer stores an electrical charge, and the 2 plates are compressed when force is applied, causing the distance between the plates to decrease. As the distance between the plates decreases, the capacitance increases, and the resulting change in voltage is measured.
>
> (Orlin & McPoil, 2000, p. 405).

This structure is depicted in figure 2. The pedar®-x insoles are made up out of many such capacitance transducers which all together form a matrix (Figure 3) which can depict pressure distribution while walking (Orlin & McPoil, 2000).

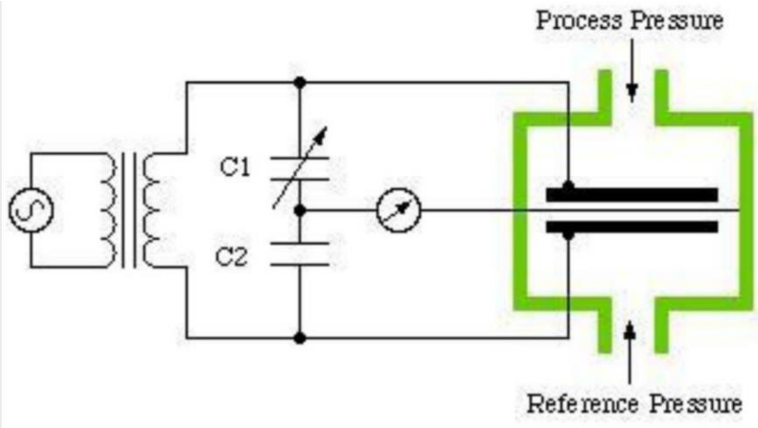

Figure 2: Example picture of a capacitance transducer
Note: Razak, Zayegh, Begg, & Wahab, 2012

For this study the sampling frequency of the pedar-x insoles was set to 100Hz. We measured only the right leg of the participants and for that purpose we used different sole sizes to fit the individual anatomical foot sizes.

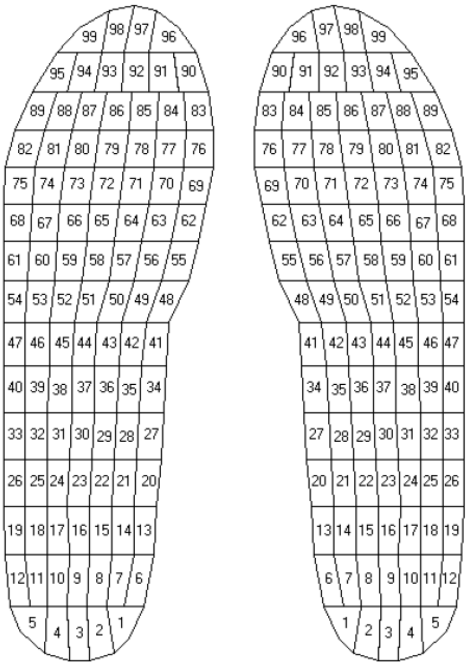

Figure 3: Matrix of the pedar insoles used in the study.
Retrieved from the german pedar handbook

2.4. Treadmill

For the backward walking task, a treadmill (cardiostrong TX50, Sport-Tiedje GmbH, Germany) was used. The speed can range from 0.8 km/h up to 20 km/h. Since the particular model cannot operate in reverse speed, the subjects positioned facing towards the back of the treadmill (Figure 4).

Figure 4: Exemplary depiction of the participant's position on the treadmill with the safety harness.

To ensure safety at all times a safety harness ("Black Diamond® vario chest harness, Salt Lake City, Utah) was used. The harness was attached to a hook mounted on the ceiling above the treadmill by means of two carabines and a climbing rope. A special knot was used to adjust the knot height depending of the anthropometrical parameters of the participants.

2.5. Walking speed

In this study we chose to let the participants walk at two different speeds as the walking speed on treadmills could have a significant effect on kinematic data (Stoquart et al., 2008). One walking speed was the same for every subject and selected by the conductor of the study and the second walking speed should represent the subject's self-selected comfortable walking speed. The determination process was chosen to be similar to the one used by Oudenhoven et al. (2019) only that the intervals in which the speed was increased and decreased were specified beforehand. For that purpose, subjects started walking at a backward walking speed of 1km/h and we increased the speed in 0.5km/h increments until the subject expressed feeling uncomfortable. Immediately after reaching the uncomfortable speed we started decreasing the speed in 0.2km/h increments until the subject felt comfortable again. This adjustment was performed for every subject individually in this study.

The fixed walking speed of 2.5km/h was determined prior by means of pilot trials by the conductor of the study. The determination criteria for the specified speed was that it should be easily manageable by every person no matter his/her anthropometrical characteristics. Nonetheless, in the literature we can find two other studies which used an almost similar speed of 2.4km/h for backward walking while examining the muscle damage induced by backward downhill walking (Nottle & Nosaka, 2005) and the effects of downhill backward walking on muscle stiffness (Corey W. Joseph et al., 2014).

2.6. Experimental Setup

The treadmill was centred under the hook in the ceiling to enable the use of the safety harness. The infrared Vicon cameras were positioned around the treadmill in different heights so every marker could be easily identified (Figure 5).

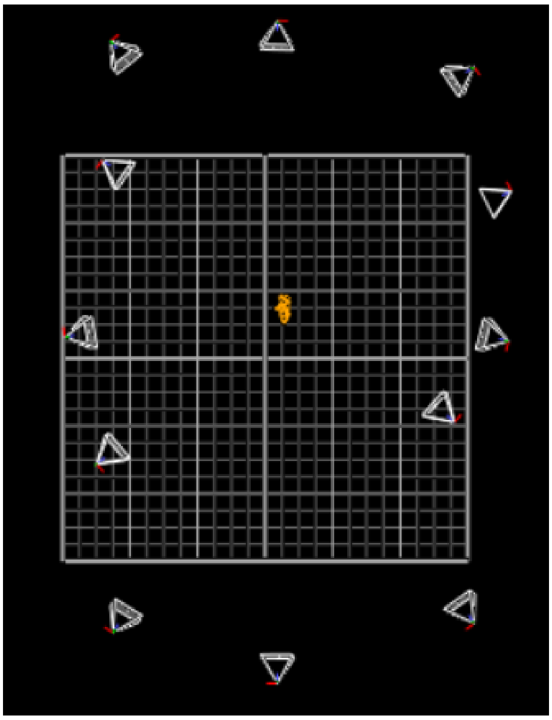

Figure 5: Overview of the camera positions in the laboratory with the subjects located in the middle (orange lines).

2.7. Experimental Protocol

Before the walking task the participants were fitted with the right size pressure insole. Subsequently the sole was connected to the pedar®-x system and calibrated.

The reflective markers for the kinematic analysis were placed as described in chapter 2.2. on the subject and the right shoe of the subject.

After marker placement the participant had to stand in neutral position for about 10 seconds in order to acquire the anatomical reference with the motion capturing system. Subsequently the participant was positioned on the treadmill facing backward and introduced to the safety harness. The height was adjusted accordingly to the height of the participant. Subsequently, the individual comfortable walking speed was determined as described in section 2.5. The whole procedure required two to three minutes and therefore the participant was given more time on the treadmill to get accustomed to that uncommon walking task. The whole procedure was realised in 5 minutes.

After the five minutes of warm-up and familiarisation process a small pause of 1 minute was given and subsequently the test was started. The participants were randomly assigned to either start walking backward with the voluntary or the predetermined speed of 2.5 km/h. The participants walked at every condition for 12 minutes while in the last ten seconds of every minute a measurement (approximately four consecutive touch-down events) was made. After the first 12 minutes, a small pause of 1 minute was given and the participants walked with the alternative walking speed.

2.8. Data processing

In the figure 6, 7 and 8 we depict an example of the kinematic data of the different lower limb angles gained through the measurements.

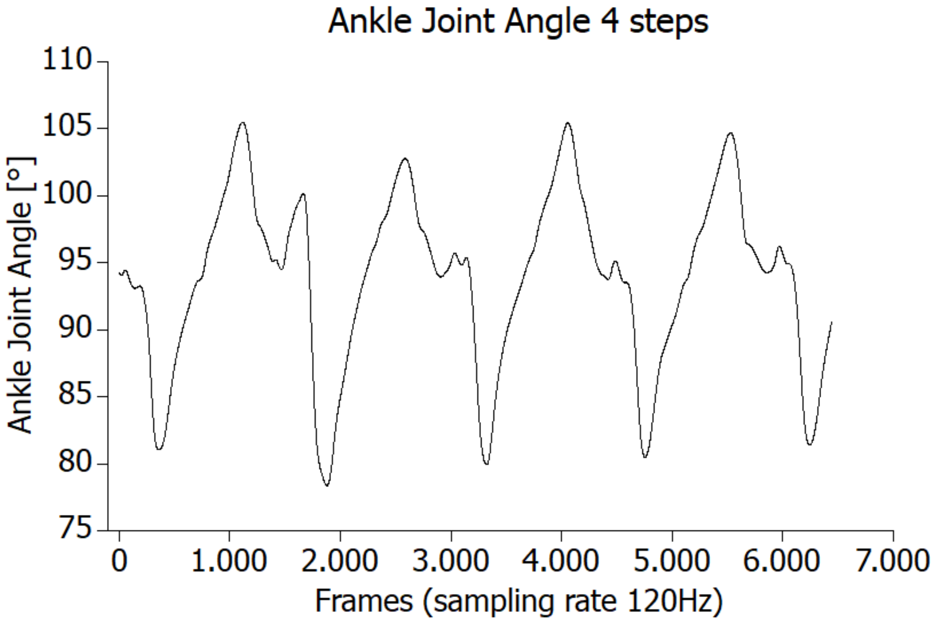

Figure 6: This is an example of the ankle joint angle development over the course of 4 steps during backward walking on the treadmill at the predetermined speed of 2.5km/h.

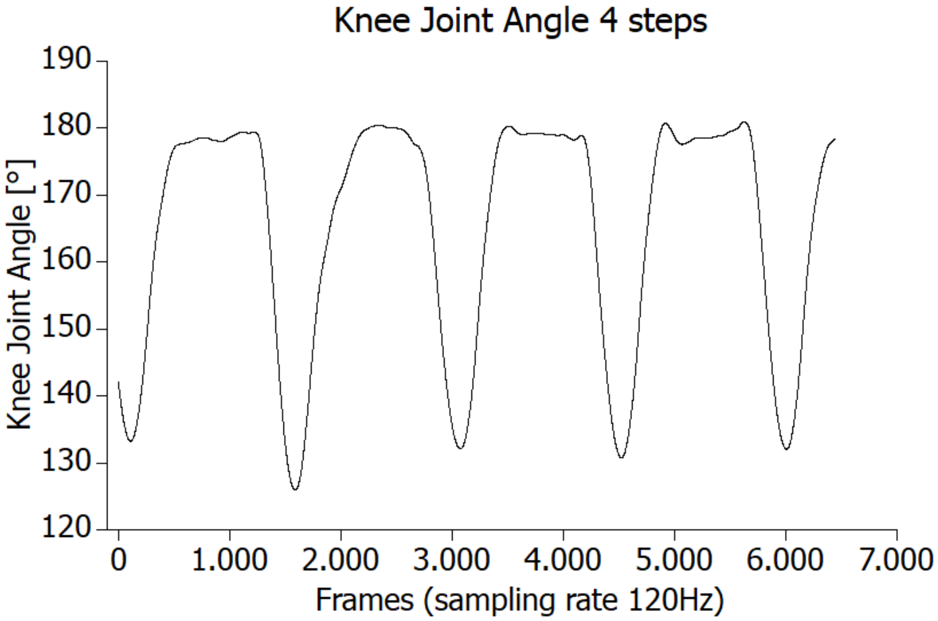

Figure 7: This is an example of the knee joint angle development of over the course of 4 steps during backward walking on the treadmill at the predetermined speed of 2.5km/h.

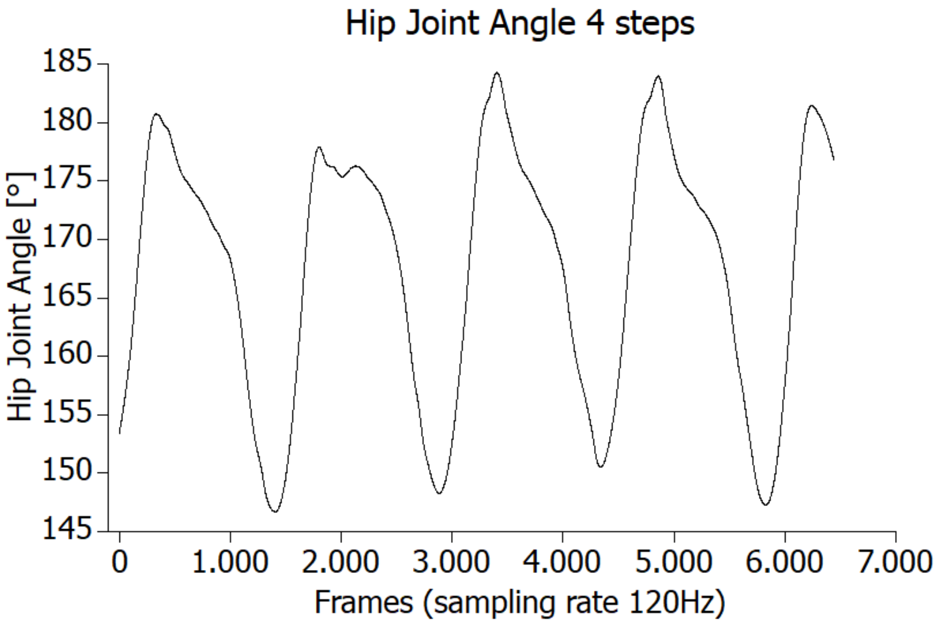

Figure 8: This is an example of the hip joint angle development over the course of 4 steps during backward walking on the treadmill at the predetermined speed of 2.5km/h.

The steps were segmented, time normalised and the mean was calculated. The average of four steps was used for further analysis. The segmentation method is described in the following section.

The kinematic data were first filtered with a zero-lag 4th order Butterworth filter with a cut of frequency individually determined (mean 13.75±0.79Hz, min 12Hz, max 15Hz) by means of residual analysis (D. A. Winter, 2009). Since the analog data (synchronization signal TTL) was captured with 1.2Khz we interpolated the kinematic data by means of cubic splines to achieve a common frequency. The reference measurement was used to identify the correct joint angles. After calculating the joint angles, we segmented (touch-down to take-off) and time normalised (Figures 9,10 and 11) all respective time series.

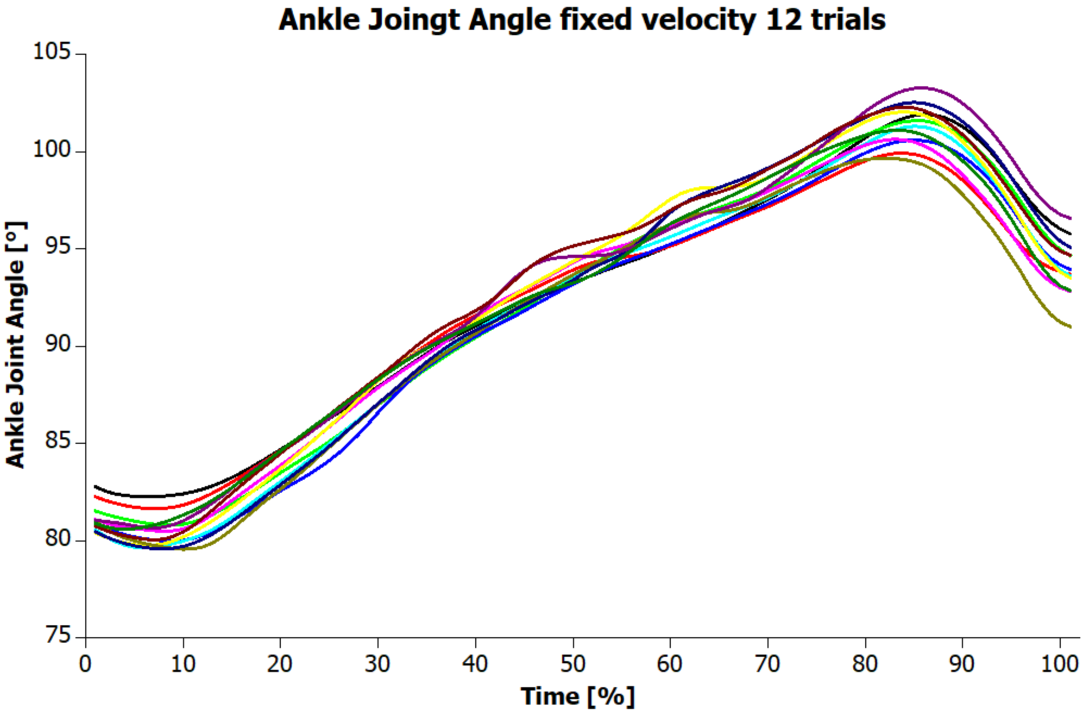

Figure 9: Development of the ankle joint angle of 12 measurements of one subject with time normalised in percent during backward walking on a treadmill at the predetermined speed of 2.5km/h.

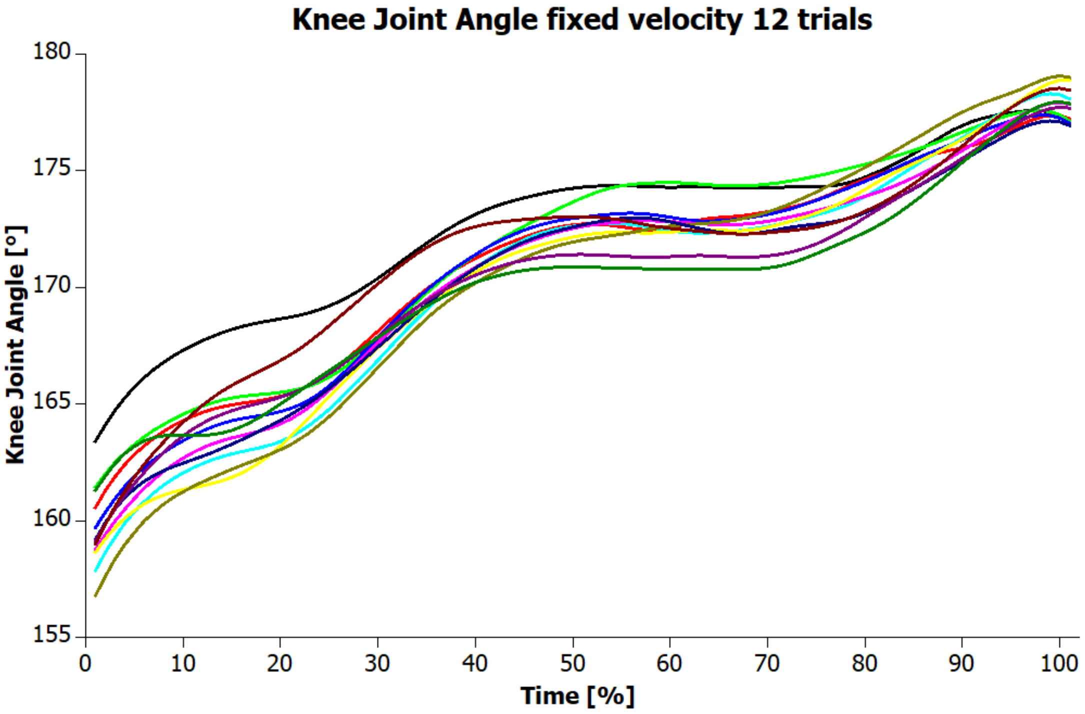

Figure 10: Development of the knee joint angle of 12 measurements of one subject with time normalised in percent during backward walking on a treadmill at the predetermined speed of 2.5km/h.

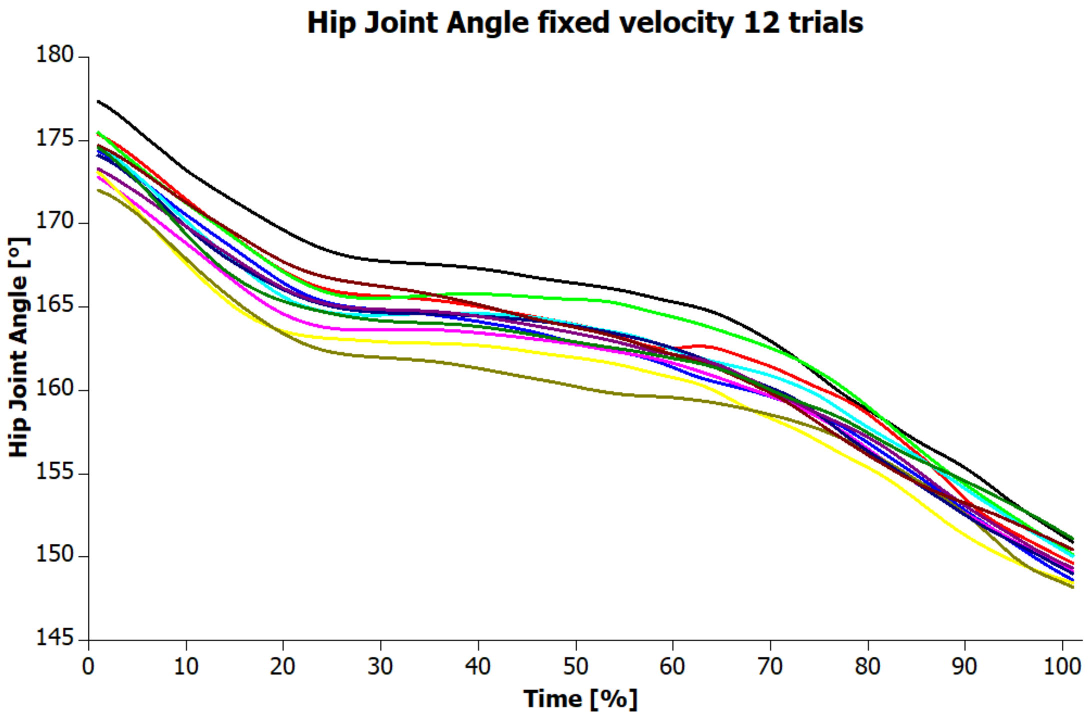

Figure 11: Development of the hip joint angle of 12 measurements of one subject with time normalised in percent during backward walking on a treadmill at the predetermined speed of 2.5km/h.

2.9. Determining touch-down and take-off

We encountered major difficulties when trying to assess the touch-down and take-off events through the pressure insoles (Figure 12A and B) and therefore we implemented an alternative approach. Figures 12A and B depict the vertical force data from the sensitive pressure insoles. Noise data when no pressure applied, made the automatic detection of the touch-down and take-off events difficult.

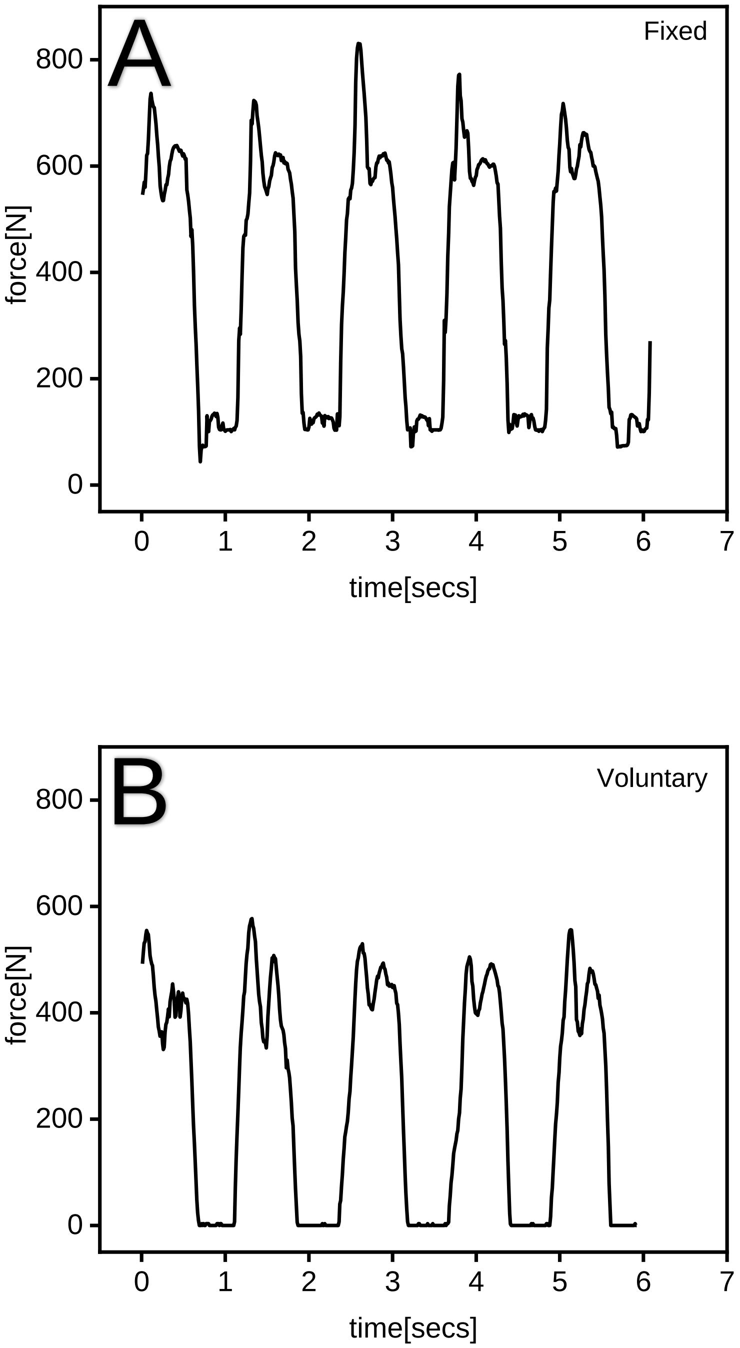

Figure 12: Exemplary vertical force data from one subject in two different conditions (fixed (A) and voluntary speed (B)).

For that purpose, we used the kinematic data provided by the motion capturing system after differentiation with the zero crossing method.

2.9.1. Take-off

To determine take-off, the data of horizontal speed gained from the calcaneus marker was used while the speed in the watching direction of the participant was defined as positive. So, when the calcaneus marker reached a target (threshold) positive velocity of 0.1m/s the foot was assumed to be off the ground. To set the threshold of 0.1m/s we first examined the kinematic data and visually (subjective) verified it and used it for the subsequent analysis. The differentiated time series of the calcaneus marker is depicted in figure 13.

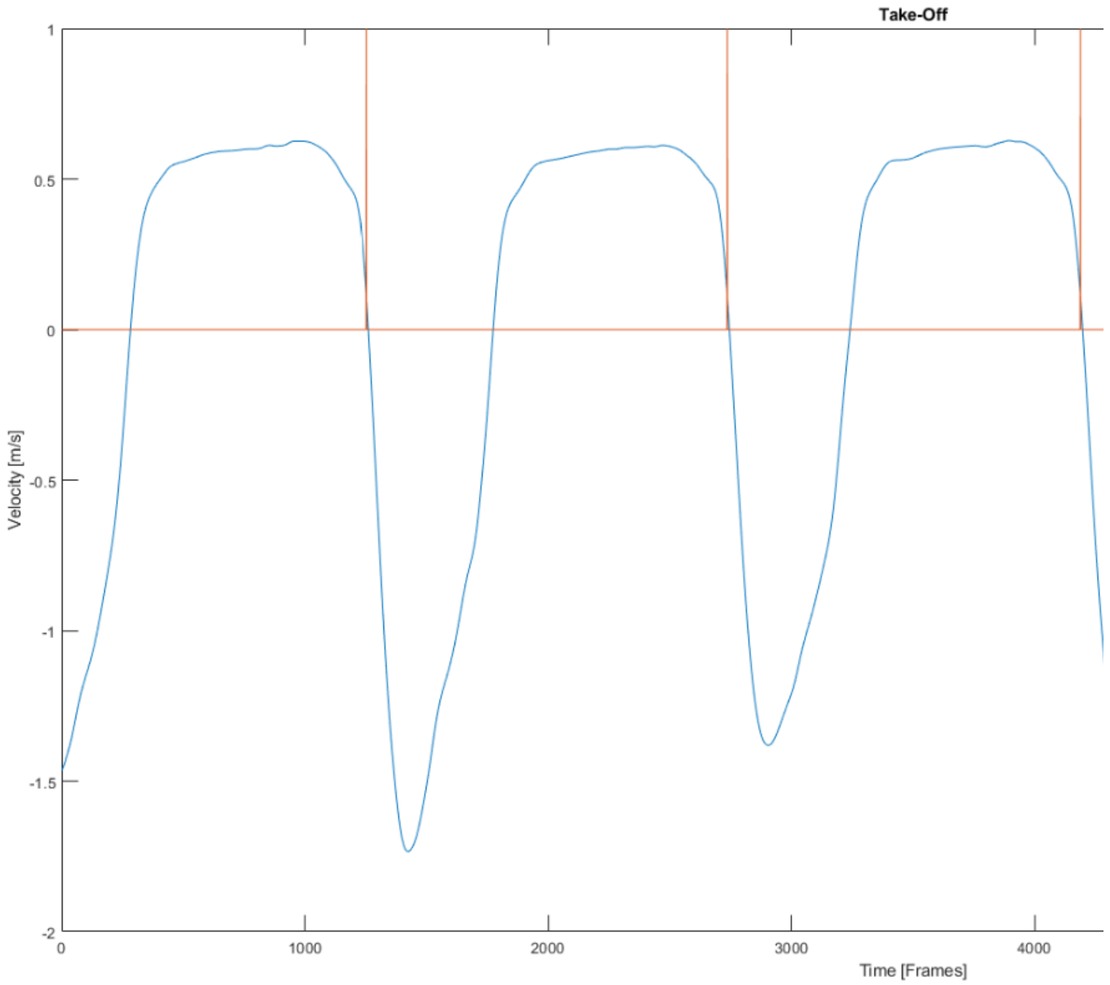

Figure 13: Exemplary process of take-off determination. The blue line depicts the horizontal speed of the calcaneus marker over three consecutive steps. The horizontal oriented red line is the speed threshold of 0.1m/s. The vertical red line indicates the point where the marker reaches the threshold speed of 0.1m/s.

2.9.2. Touch-down

To determine the touch-down event we used a similar procedure. Instead of the horizontal speed of the calcaneus, the vertical speed of the fifth metatarsal marker was used. As long as the foot was moving towards the ground, the vertical speed of the marker at the fifth metatarsal was negative and went towards zero when touching the treadmill. The threshold value of the vertical speed of the marker positioned at the fifth metatarsal was set to <-0.05m/s. Again, the threshold setting was performed after visually examining and subjectively verifying the kinematic data of the 5th metatarsal. This process is depicted in figure 14.

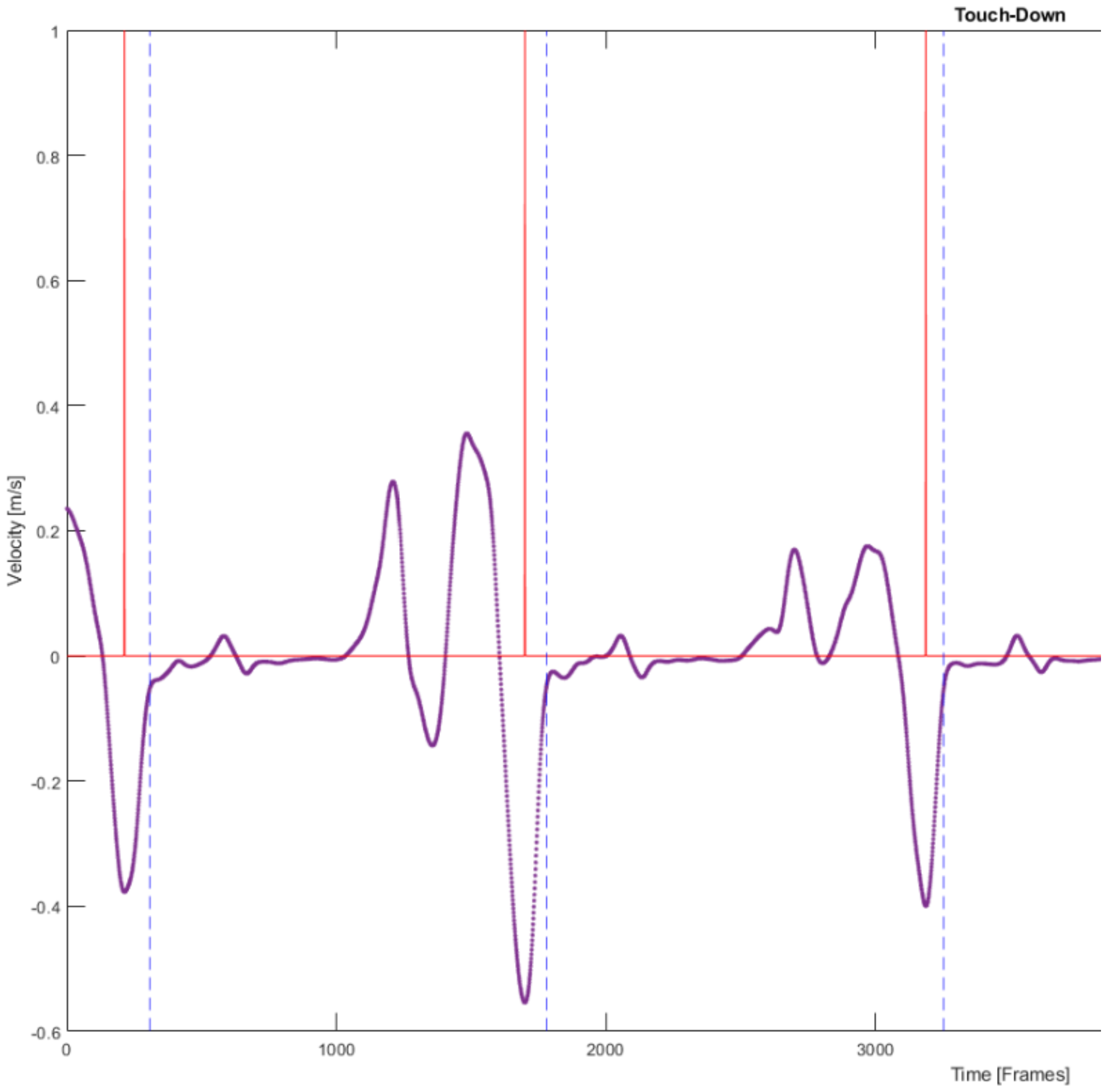

Figure 14: Process of touch-down determination. The purple line depicts the vertical speed development of the marker placed at the 5th metatarsal over two consecutive steps. The horizontal oriented red line is the speed threshold of -0.05m/s. The vertical red line indicates the point where the marker reaches the speed of -0.05m/s.

The kinematic method used in the present study could be subject of a systematic error therefore contact time and furthermore the beginning and the end of the kinematic variables could possibly be erroneous. Nonetheless, since the same method was applied to all subjects a constant error in the kinematic variables’ estimations should be expected. Additionally, we plan a validation of the aforementioned method with other measuring systems (High Speed camera, force platforms) in order to accurately estimate the error magnitude.

The present kinematic determination of the gait events is not unusual in the scientific community. Zeni, Richards, & Higginson (2008) used a similar method to determine touch-down and take-off instances while investigating forward walking. They used the positive and negative velocity of the calcaneus marker. When the calcaneus marker moved forward and gained positive speed the authors defined it as take-off. On the other hand, touch-down was defined the instance where the same marker gained negative velocity

Additionally Zeni et al. (2008) reported that the maximum error of this method when testing healthy subjects was three frames, which corresponds to 0.05 seconds due to recording kinematic data with 60 Hz.

2.10. Statistical analysis

The statistical analysis was performed with the IBM SPSS statistic program. We used the One-sample T-test to determine whether the fixed and the voluntary walking speed were significantly different. To test if the data was normally distributed, we conducted a Shapiro-Wilk-Test. In case of normally distributed data a one-way ANOVA with repeated measurement was used. With significant time effects on the dependent variables, we further tested the kinematic variables with a Bonferroni correction to identify the time points where the significance was present. If the data was not normally distributed, the non-parametric Friedmann test was used to determine time effects and in case of significant effects, the Wilcoxon signed-rank test was conducted.

3. Results

In this chapter, the results of the conducted study are presented. Since the majority of the examined parameters did not show any significant difference, we are presenting only the parameters that were affected by the trial time. The rest of the parameters are displayed in the appendix. Table 1 depicts the anthropometric characteristics of the participants.

Table 1: Average ± standard deviation of age, mass and height of all, the female and male participants of the study are shown.

	Overall (n=20)	Female (n=8)	Male (n=12)
Age [years]	24.9±3.5	24.3±4.1	25.3±3.1
Mass [kg]	69.6±10.6	60.1±5.3	75.8±8.2
Height [m]	1.76±0.07	1.69±0.04	1.81±0.04

The one sample T-Test revealed a significant statistical difference ($p < 0.05$) between the average self-selected walking speed (2.69±0.37km/h) and the predetermined speed (2.5km/h).

In Table 2 the results of the *knee joint angle at touch-down* at fixed and voluntary speed over 12 trials of all, female and male participants are depicted. The statistical analysis revealed a significant effect (Friedmann test p = 0.046) of time for the male participants while walking backward at voluntary walking speed. The Wilcoxon test showed that there were significant differences between trials 1, 4 9, 11 and 12.

Table 2: The mean values and standard deviation for the knee angle at touch-down are shown over 12 minutes. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). The superscript numbers specify the significant difference (p<0.05). between the actual and the indicated trial(s).

TD_KA	FIXED			Voluntary		
Trial	Overall [°]	Male [°]	Female [°]	Overall [°]	Male [°]	Female [°]
1	155.75 ± 4.92	156.24 ± 5.65	155.03 ± 3.81	155.83 ± 5.32	156.92 ± 6,27 ^{11}	154.18 ± 3.15
2	156.01 ± 5.68	157.15 ± 6.31	154.31 ± 4.42	155.24 ± 4.64	156.39 ± 5.30	153.52 ± 2.92
3	155.78 ± 5.17	156.92 ± 5.61	154.06 ± 4.19	155.38 ± 4.26	156.24 ± 4.53	154.10 ± 3.71
4	156.14 ± 4.89	156.56 ± 5.32	155.51 ± 4.44	155.81 ± 5.51	156.99 ± 6,32 ^{9,11,12}	154.05 ± 3.72
5	156.24 ± 4.99	156.46 ± 5.69	155.91 ± 4.07	155.33 ± 5.40	156.45 ± 5,68 ^{9}	153.65 ± 4.81
6	155.57 ± 4.85	156.42 ± 5.42	154.31 ± 3.84	155.11 ± 5.30	156.00 ± 5.99	153.79 ± 4.05
7	156.39 ± 5.51	156.71 ± 6.66	155.91 ± 3.51	154.86 ± 5.83	156.10 ± 6.43	153.02 ± 4.58
8	155.16 ± 5.08	156.02 ± 5.85	153.87 ± 3.61	154.46 ± 5.66	156.04 ± 6.21	152.10 ± 3.97
9	155.39 ± 5.18	155.94 ± 6.28	154.56 ± 3.07	154.31 ± 4.81	155.38 ± 5,64 ^{4,5}	152.70 ± 2.83
10	154.88 ± 4.68	155.39 ± 5.74	154.10 ± 2.56	155.31 ± 5.29	156.68 ± 5.90	153.27 ± 3.65
11	155.08 ± 4.95	155.92 ± 5.64	153.81 ± 3.68	154.36 ± 5.07	155.50 ± 5,16 ^{1,4}	152.64 ± 4.71
12	154.67 ± 4.15	154.82 ± 5.02	154.45 ± 2.64	154.78 ± 5.23	155.92 ± 6,19 ^{4}	153.08 ± 2.93

In table 3 the results of the *contact time* at fixed and voluntary speed over 12 trials of all, female and male participants is depicted. The statistical analysis revealed a significant effect (Friedmann test p = 0.042) of trial time on the contact time for the female participants at fixed walking speed. The Wilcoxon test showed that there was a significant difference (p<0.05) between trials 1, 2, 3, 5, 6, 7, 8, 9, 10, 11 and 12.

Table 3: The mean values and standard deviation for contact time are shown over 12 minutes. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). The superscript numbers specify the significant difference (p<0.05) between the actual and the indicated trial(s).

ConTime	FIXED			Voluntary		
Trial	**Overall [s]**	**Male [s]**	**Female [s]**	**Overall [s]**	**Male [s]**	**Female [s]**
1	0.712 ± 0.078	0.740 ± 0.070	0.670 ± 0,072 ^{2,3,6,7,8,10,11}	0.693 ± 0.080	0.701 ± 0.078	0.680 ± 0.086
2	0.727 ± 0.075	0.749 ± 0.067	0.694 ± 0,078 ^{1}	0.699 ± 0.077	0.711 ± 0.076	0.681 ± 0.080
3	0.721 ± 0.076	0.739 ± 0.072	0.695 ± 0,080 ^{1}	0.699 ± 0.073	0.709 ± 0.077	0.685 ± 0.069
4	0.723 ± 0.084	0.746 ± 0.075	0.687 ± 0.090	0.705 ± 0.072	0.715 ± 0.070	0.689 ± 0.076
5	0.728 ± 0.082	0.757 ± 0.075	0.684 ± 0,077 ^{6,8}	0.706 ± 0.075	0.713 ± 0.074	0.697 ± 0.082
6	0.729 ± 0.084	0.749 ± 0.085	0.698 ± 0,076 ^{1,5,9,7}	0.707 ± 0.073	0.711 ± 0.068	0.702 ± 0.084
7	0.728 ± 0.083	0.752 ± 0.078	0.693 ± 0,080 ^{1}	0.706 ± 0.082	0.708 ± 0.076	0.703 ± 0.096
8	0.734 ± 0.074	0.756 ± 0.070	0.702 ± 0,072 ^{1,5,9,10,12}	0.711 ± 0.086	0.708 ± 0.081	0.715 ± 0.098
9	0.721 ± 0.077	0.745 ± 0.065	0.685 ± 0,082 ^{6,8,11}	0.713 ± 0.083	0.723 ± 0.074	0.697 ± 0.097
10	0.726 ± 0.077	0.752 ± 0.069	0.688 ± 0,077 ^{1,6,8}	0.705 ± 0.081	0.703 ± 0.074	0.707 ± 0.097
11	0.738 ± 0.081	0.758 ± 0.080	0.707 ± 0,076 ^{1,9}	0.719 ± 0.079	0.723 ± 0.075	0.712 ± 0.089
12	0.726 ± 0.076	0.751 ± 0.069	0.690 ± 0,074 ^{8}	0.712 ± 0.087	0.721 ± 0.080	0.699 ± 0.101

In table 4 the results of the *Procrustes Analysis of the knee joint angle* at fixed and voluntary speed over 11 paired trials of all, male female and participants are depicted. The statistical analysis revealed a significant effect (Friedmann test p = 0.043) of time on the examined variable. The Wilcoxon test showed significant difference (p<0.05) between trials 1, 3, 4, 8, 9 and 11 for all participants at voluntary speed (** <0.01).

*Table 4: The mean Procrustes distances / root mean square distances and standard deviation are shown for the knee joint angle over 11 trials. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). The superscript numbers specify the significant difference (p<0.05). between the actual and the indicated trial(s). (** <0.01)*

PC_KA	**FIXED**			**Voluntary**		
Trial	**Overall**	**Male**	**Female**	**Overall**	**Male**	**Female**
1	0.038 ± 0.031	0.032 ± 0.033	0.048 ± 0.029	0.014 ± 0,009^{8}	0.046 ± 0.040	0.039 ± 0.034
2	0.035 ± 0.034	0.037 ± 0.031	0.032 ± 0.040	0.022 ± 0.022	0.055 ± 0.090	0.045 ± 0.071
3	0.048 ± 0.052	0.040 ± 0.036	0.060 ± 0.072	0.015 ± 0,015^{4}	0.064 ± 0.135	0.047 ± 0.106
4	0.056 ± 0.048	0.052 ± 0.047	0.062 ± 0.050	0.026 ± 0,046^{3,8,11**}	0.063 ± 0.069	0.059 ± 0.061
5	0.032 ± 0.026	0.028 ± 0.018	0.038 ± 0.036	0.019 ± 0.019	0.035 ± 0.031	0.027 ± 0.027
6	0.035 ± 0.037	0.037 ± 0.045	0.032 ± 0.025	0.014 ± 0.014	0.027 ± 0.017	0.029 ± 0.022
7	0.043 ± 0.042	0.049 ± 0.046	0.033 ± 0.037	0.022 ± 0.037	0.042 ± 0.045	0.031 ± 0.038
8	0.060 ± 0.084	0.041 ± 0.036	0.088 ± 0.126	0.011 ± 0,011^{1,4}	0.026 ± 0.024	0.024 ± 0.022
9	0.048 ± 0.053	0.035 ± 0.028	0.067 ± 0.075	0.013 ± 0,009^{11}	0.057 ± 0.091	0.046 ± 0.071
10	0.031 ± 0.021	0.034 ± 0.022	0.027 ± 0.022	0.013 ± 0.010	0.034 ± 0.028	0.033 ± 0.024
11	0.034 ± 0.022	0.035 ± 0.018	0.031 ± 0.028	0.017 ± 0,017^{4**,11}	0.021 ± 0.020	0.024 ± 0.031

In table 5 the results of the *Procrustes Analysis of the hip joint angle* at fixed and voluntary speed over 11 paired trials of all, male and female participants are depicted. The statistical analysis revealed a significant effect (Friedmann test p = 0.043) of time on the examined variable. The Wilcoxon test showed significant difference ($p<0.05$) for all participants at fixed speed at the trials 1, 2, 5, 6, 9 10 and 11 (** <0.01).

*Table 5: The mean Procrustes distances / root mean square distances and standard deviation are shown for the hip joint angle over 11 trials. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). The superscript numbers specify the significant difference (p<0.05) between the actual and the indicated trial(s) (** <0.01).*

PC_HA	FIXED			Voluntary		
Trial	Overall	Male	Female	Overall	Male	Female
1	0.023 ± $0,021^{6}$	0.021 ± 0.017	0.026 ± 0.025	0.022 ± 0.029	0.029 ± 0.035	0.013 ± 0.010
2	0.018 ± $0,017^{6,10}$	0.021 ± 0.018	0.015 ± 0.015	0.032 ± 0.069	0.044 ± 0.089	0.014 ± 0.009
3	0.018 ± 0.015	0.020 ± 0.017	0.015 ± 0.009	0.026 ± 0.049	0.031 ± 0.063	0.017 ± 0.009
4	0.018 ± 0.011	0.019 ± 0.012	0.017 ± 0.011	0.028 ± 0.030	0.025 ± 0.031	0.032 ± 0.031
5	0.019 ± $0,019^{6}$	0.016 ± 0.015	0.024 ± 0.024	0.015 ± 0.011	0.016 ± 0.012	0.013 ± 0.009
6	0.012 ± $0,013^{1,2,5,10**,11}$	0.012 ± 0.011	0.013 ± 0.017	0.022 ± 0.024	0.024 ± 0.031	0.019 ± 0.012
7	0.019 ± 0.019	0.021 ± 0.017	0.015 ± 0.022	0.026 ± 0.044	0.018 ± 0.019	0.037 ± 0.067
8	0.018 ± 0.015	0.017 ± 0.013	0.020 ± 0.017	0.017 ± 0.011	0.017 ± 0.013	0.017 ± 0.007
9	0.019 ± $0,016^{10}$	0.016 ± 0.013	0.023 ± 0.020	0.027 ± 0.027	0.023 ± 0.026	0.033 ± 0.028
10	0.030 ± $0,027^{2,6**,9}$	0.030 ± 0.027	0.030 ± 0.029	0.019 ± 0.017	0.018 ± 0.021	0.020 ± 0.011
11	0.024 ± $0,024^{6}$	0.026 ± 0.022	0.021 ± 0.029	0.025 ± 0.037	0.020 ± 0.028	0.032 ± 0.049

For clarity purposes the contact time development over 12 trials of only the female participants at the backward walking speed of 2.5km/h is depicted in the figure 15.

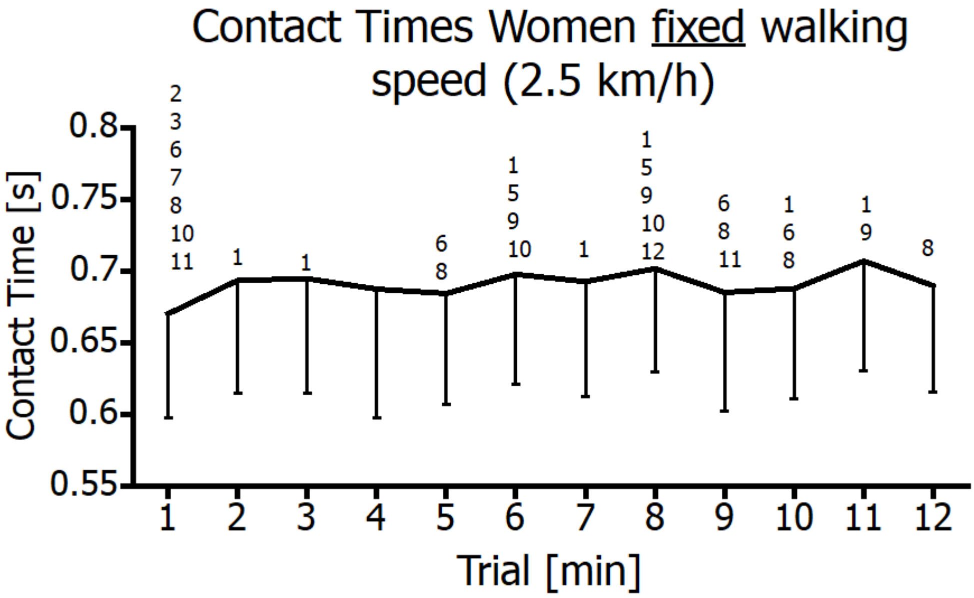

Figure 15: The contact times of the female participants at fixed walking speed of 2.5km/h over 12 trials are depicted. The numbers above each measurement describe the significant difference between the actual and the corresponding trial (p<0.05).

For clarity purposes in figure 16 the results of the Procrustes Analysis of the hip joint angle of all participants at the predetermined speed (2.5km/h) are depicted.

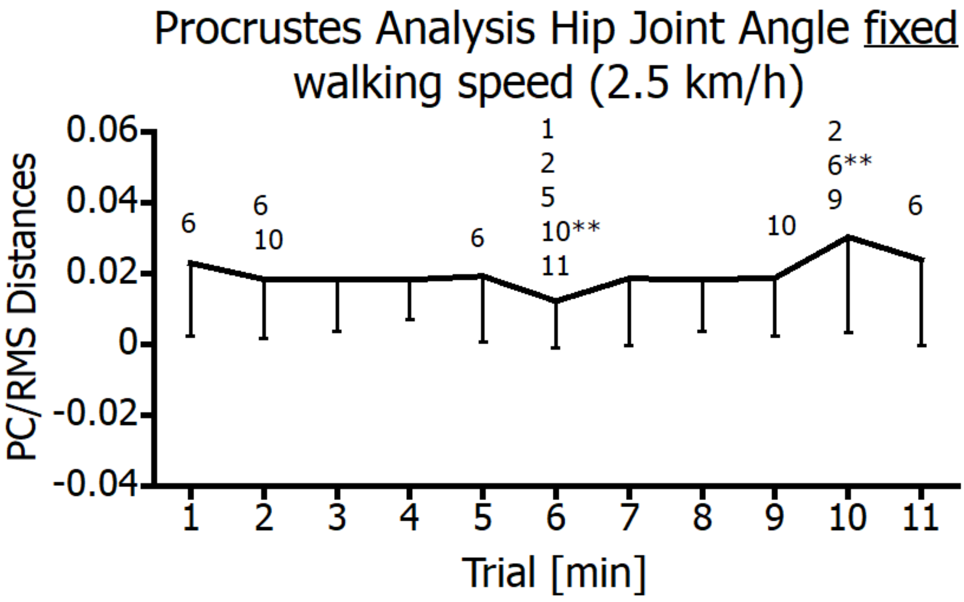

*Figure 16: The mean Procrustes distances of the hip joint angle at fixed walking speed of 2.5km/h of all participants are depicted. On the x-axis each trial number represents the comparison between two consecutive trials in pairs. Numbers above represent the statistical significant (p<0.05) difference between the respective paired trial (** <0.01).*

For clarity purposes, the results of the knee joint angle at touch-down of the male participants at voluntary walking speed are depicted in figure 17.

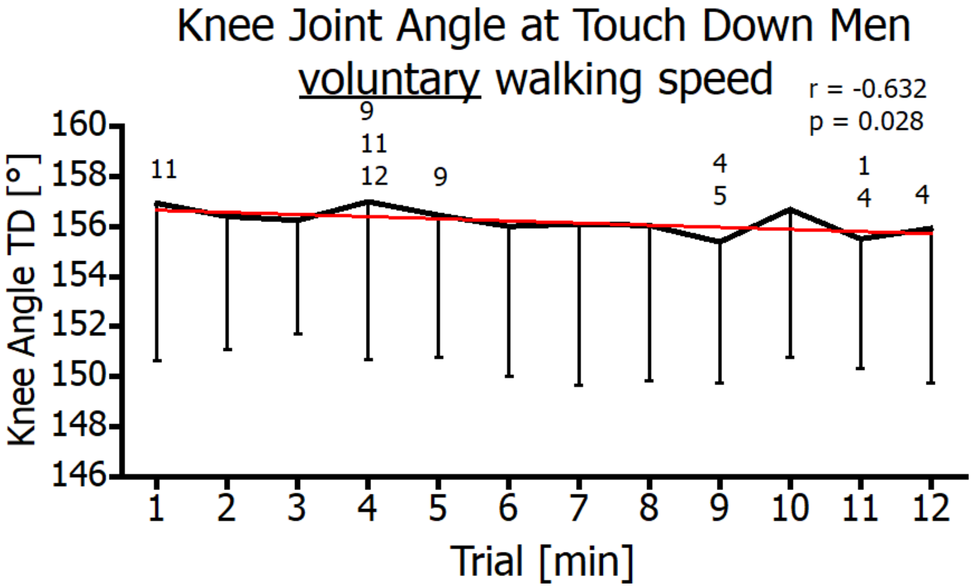

Figure 17: The knee joint angle at touch-down of the male participants at voluntary walking speed (2.69±0.37km/h) over 12 trials is depicted. The numbers above each trial describe a significant difference (p<0.05) between the actual and the corresponding trial. Pearson correlation showed a significant (p=0.028) negative correlation (r= -0.632) of knee joint angle at touch-down with time.

For clarity purposes, the figure 18 shows the results of the Procrustes Analysis of the knee joint angle at voluntary walking speed of all participants.

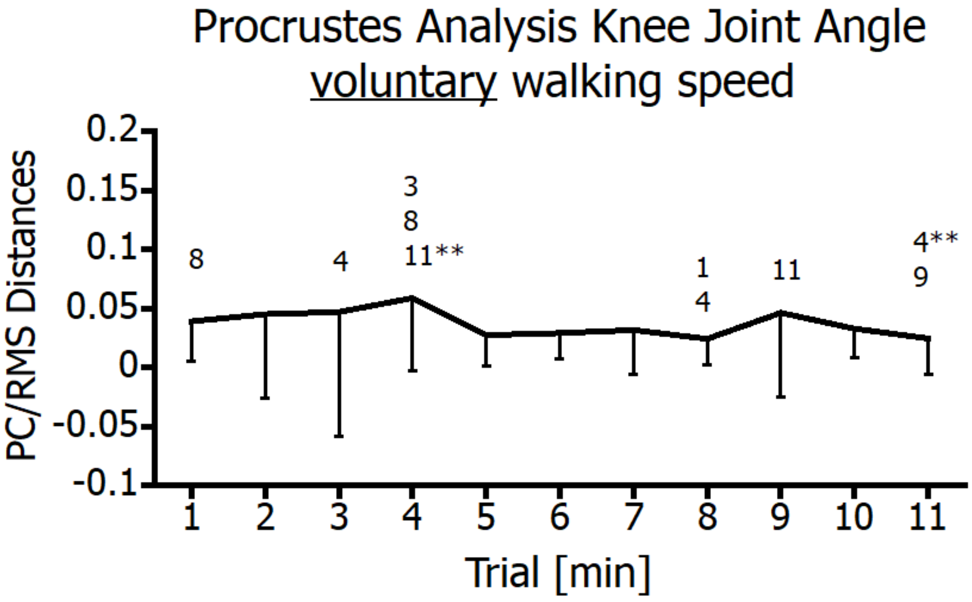

*Figure 18: The Procrustes distances of the knee joint angle at voluntary walking speed (2.69±0.37km/h) of all participants are depicted. On the x-axis each trial number represents the comparison between two consecutive trials in pairs. Numbers above represent the statistical significant (p<0.05) difference between the respective paired trial (** <0.01).*

4. Discussion

4.1. Main finding

The main outcome of this study is that for the majority of the discrete spatio-temporal parameters no familiarisation time is needed in order to obtain stable kinematics. In this study, only four of the 102 examined parameters exhibited a time effect. Especially, the a) female contact time at fixed speed 2.5km/h, b) Procrustes distances of the hip angle of all participants at voluntary speed c) the male knee joint angle at voluntary walking speed and d) the Procrustes distances of the knee angle of all participants at voluntary walking speed require an familiarisation time before any measurement can be conducted.

Meyer et al. (2019) came to almost analogous results in his study where he investigated the familiarisation time in forward walking. The authors found that 10 of the 26 kinematic parameters remained stable from the beginning of the trial and showed no signs of differentiation which could be an indication of habituation. The other 16 kinematic parameters became stable after 6-7 minutes. At this point, we have to mention that Meyer et al. (2019) defined "familiarisation" as the point where four consecutive measurements showed no significant difference to the initial one. Nonetheless, although our methodological approach was more sensitive to changes, it appears that backward walking is not subject of rigorous alterations.

4.2. Contact time

The higher sensitivity of the present method can be seen in the *female contact times* at fixed speed (Figure 15). There was a significant effect of trial time instance on the foot contact time during the backward walking. This indicates that the imposed fixed speed affects the walking pattern of the participants from short (1 to 10-11min) to longer contact times but this result is in contrast to the findings at the voluntary speed (Table 3) where no significant differences were found. We performed a one sample T-test comparing the female fixed and voluntary speed that revealed no significant differences ($p>0.05$) between both conditions (2.5km/h and 2.61±0.37km/h respectively). The reason for this differential outcome cannot be explained with the present methodological approach.

Additionally, although significant differences could be found between the female contact times at voluntary speed, we could not identify a clear tendency for stable contact times during the backward walking task. Also, in conjunction with the other findings (Table 3 and Appendix Table: 17) where the contact and stride times of overall and male participants are depicted, we can conclude that backward walking, after 5 min specific warmup, leads to stable contact times.

In an earlier study that was focussed on the habituation of forward walking on a treadmill Van de Putte et al. (2006) examined the contact times of the participants. To determine the gait events, the authors used dynamic data and in particular, in their study they used an instrumental two-belt treadmill with integrated force plates into each treadmill belt. In their study the contact times ranged from 0.75 to 0.775 seconds which is almost similar to our findings (overall at fixed speed: minimum 0.712s – maximum 0.738s, mean 0.726 ±0.007 and at voluntary speed: minimum 0.693s – maximum 0.719, mean 0.706±0.007). Their results showed no significant change in contact times over a 15-minute forward walking test. This result is similar to ours, which is an indication that at low walking speeds the variation of temporal parameters is marginal.

4.3. Stride time

Similar results (no effect) were found when we compared the *stride time* between the different conditions and sub-groups (Appendix: Table 17). Therefore, in conjunction with the results of the contact time we can conclude that the backward walking, at both specific speeds, does not affect the stability of the aforementioned temporal parameter.

4.4. Hip joint

Also, at the hip joint all the discrete values of the examined parameters (maximum hip angle, minimum hip angle, hip angle at touch-down and hip angle at take-off) showed no significant effect over time (Appendix: Table 10-13). Additionally, the same result was found for the subgroups (male female).

While the discrete analysis revealed no differences between the trials, the *Procrustes analysis of the hip joint angle at fixed speed (2.5km/h) of all participants* showed an effect of time (Figure 16). The subsequent Wilcoxon test showed that the hip joint angle at the beginning (pair trials 1 and 2), in the middle (pair trial 6) and at the end (pair trails 9-11) where significantly different. This result indicates that there is a time window where the hip joint kinematics are stable and can be used for comparison purposes. In particular, the stable hip joint kinematics can be obtained between the minute 3 until 5 and from the minute 7 until 9.

Similar results can be found in the study of Meyer et al. (2019) where the *hip joint Range of Motion* (ROM) was examined during 10 min forward walking. The authors concluded that no familiarisation of the hip joint occurred over the measurement duration. Accordingly, also the symmetry parameter expressed as the *left/right Hip ROM Ratio* exhibited no familiarisation process. It must be mentioned that the assessment method of Meyer et al. (2019) differs strongly from the one adopted in the present study. While we took measurements after every minute and analysed the mean of four gaits, Meyer et al. (2019) recorded the whole walking process and segmented every 25 gait cycles in a bin (total 20 bins) and compared them to the initial one. From the 26 parameters 10 exhibited no familiarisation, while 16 walking parameters showed an early familiarisation period that was followed by a plateau. It must be also added the mean familiarisation period for all 16 walking parameters were between 4-6 minutes.

In another study Taylor et al. (1996) also investigated the hip and pelvis while forward walking on the treadmill in two different walking speeds (self-selected speed and 60% of the self-selected speed). The researchers focused on the lumbar spine and the pelvis angles and for that purpose they used the mean of 6 gait cycles of every 2 min for a total duration of 10 min. The angular movement of the lumbar spine and pelvis was calculated by the maximum minus the minimum angle during the gait cycle. The authors further assessed the reliability of the angular movements by means of Intraclass Correlation Coefficient (ICC) and concluded that stable kinematics were established at minute 4 (ICC=0.83) since no higher values could be reached in the subsequent trials. Therefore, the authors stated that reliable measurements could be obtained from that time on.

Although both aforementioned studies examined the hip joint motion in forward direction, they showed almost similar results to the present study. We could also not find any familiarisation point in the discrete kinematic parameters: 1) minimum hip angle 2) maximum hip angle 3) hip angle at touch-down 4) hip angle at take-off and therefore we can conclude that the hip joint appears to move stable during the backward motion. But additional examination of the complete hip motion by means of Procrustes analysis revealed that a) the curve path of the hip joint presents great similarity across the 12 instances (Procrustes values ~0.02) and b) although that high similarity exists the curve paths demonstrated significant differences between instances. Therefore, we can additionally state that when the complete hip joint curve path during backward walking is subject of research, stable kinematics can be obtained after 3 min of walking time (excluding 5 min backward walking warmup). The present results apply to the fixed speed (2.5 km/h) and not to the self-selected one (2.69±0.37km/h). We speculate that humans exhibited greater hip joint movement adjustments in order to stabilize the trunk when they are not walking on their preferred speed. Nonetheless this hypothesis must be verified in future studies.

4.5. Knee joint

Almost similar results to the hip joint discrete values could be found at the knee joint during the backward walking. In particular, no effect of time was found on the 1) *minimum knee angle*, 2) *maximum knee angle* and the 3) *knee angle at take-off for all participants or subgroups* (Appendix: Table 14-16). Only the discrete parameter “*knee angle at touch-down*” showed significant effect for the male participants at voluntary speed (Table 2). There was also a significant negative trend (r=-0.632, p=0.028) of the *knee angle at touch-down*, which implies a minor readjustment of knee joint in dependence of the exercise duration (Figure 17). Nonetheless, the absolute knee joint angle difference between trial 1 and 11 was ~1.5° and therefore it is questionable if that minor difference can have any clinical significance. Additionally, although all other discrete parameters exhibited no significant alterations over time, the knee joint angle at touch-down appears to behave stable after minute 6 until 12 which could be theoretically used as a measuring point. Again, the absolute difference of men's knee joint angle at voluntary speed in minute 6 and 12 is ~0.18° and therefore the clinical significance of that adjustment is questionable. According to the above results we can conclude that stable knee joint discrete parameters can be obtained as soon as the first minute (excluding the 5 min backward walking warmup) independent of gender or speed during backward walking.

Also, in this examination the discrete knee joint parameters and the complete knee joint curve paths showed differential outcomes. In our study the *Procrustes Analyses* on the voluntary speed showed that there is an effect of time in the *complete knee joint curve path*. Although the similarity of the curve paths was among all trials very high (~0.017) significant differences were observed (Figure 18). It appears that stable kinematics during backward walking at voluntary speed can be obtained after the 5th minute (excluding the 5 min backward walking warmup). Although this result appears to coincide with the results from the men's knee joint angle at touch-down (discrete value) at voluntary speed, we have to distinguish between those two parameters since they represent different assessments. It is difficult to estimate the influence of the discrete parameter on the overall curve path. It is possible in future studies that with an additional methodological approach like the "Statistical Parametric Mapping" we can identify the regions in the curve path, in which significant differences are present (Hughes-Oliver et al., 2019)

Since no other study examined the familiarisation process during backward walking, we are comparing our findings with studies that were conducted in forward motion. For example, Van de Putte et al. (2006) investigated the habituation of participants during forward walking on several knee joint parameters. The authors examined the *knee flexion and extension*, *abduction and adduction and internal and external tibial rotation*. Additionally they defined distinct gait phases (stance phase maximal flexion, heel strike, swing phase maximal flexion and maximal extension before toe-off) in order to analyse the kinematic parameters (Van de Putte et al., 2006).

In their study the parameter knee *extension/flexion at touch-down* did not show any significant difference over time. The parameter was stable from the moment when the treadmill reached its target speed. The only parameter which has been affected by the walking time was the *stride length*. The authors found that the stride length needed 10 minutes in order to become stable and reproducible. The authors concluded that for young and healthy individuals who are not accustomed to the treadmill a prior 10-minute treadmill warm up is adequate to record immediately stable and reproducible three-dimensional knee kinematics and spatiotemporal data.

The findings of Van de Putte et al. (2006) in forward motion are comparable with our study since we also could not find any significant effect of time on the knee parameters. Following the conclusion of the Van de Putte et al. (2006), we can also hypothesise that the lack of differences in our study could be due to the prior 5-minute warm up. In particular also, the parameter *knee joint angle at touch-down by men at voluntary walking speed* (Figure 17) showed stability (no significant difference) after the 5th minute and therefore we can conclude that the prior 5-minute warm up affected the examined parameter.

In another study Matsas et al. (2000) focused also on the knee kinematics during 15 minute forward walking on a treadmill. The authors examined the *knee angles at a) initial contact, b) midstance and c) initial swing* after averaging 6 gait cycles every 2 minutes. No warm-up or familiarisation time on the treadmill was given to the participants. The authors concluded that highly reliable knee kinematics and temporal-distance gait measurements [intraclass correlation coefficient (ICC 0.93) can be obtained after 6 minutes of forward treadmill walking.

The results of Matsas et al. (2000) and Van de Putte et al. (2006) coincide with our findings on backward walking indicating that in general if 5-10 minutes of familiarisation time is given to the subjects stable and reproducible discrete kinematics can be obtained.

Also the study of Meyer et al. (2019) showed no form of familiarisation in the *knee joint range of motion* and the *knee range of motion ratio* (comparison of the ROM between the two knee joints left and right) during 10 min forward walking. While the authors did not grant the participants an acclimatisation period on the treadmill, similar to Matsas et al. (2000), they did not find any form of familiarisation in the aforementioned kinematic parameters. The reason for discrepancy could lay in the implemented assessment method. Meyer et al. (2019) used 25 consecutive strides as a bin and defined “familiarisation” as the time point where ≥4 consecutive bins were not statistically different from the initial one. One bin lasts on average 25 sec and therefore it is possible that short term kinematic adaptations could not be detected. Nonetheless, with this method other kinematic variables such as ankle range of motion and step length showed adaptational phenomena.

4.6. Ankle joint

We did not find any adaptation phenomena on the selected *ankle joint discrete parameters* as well as on the *curve path of the ankle joint angle (Procrustes Analysis)* in all participants and subgroups. Other studies (Meyer et al., 2019; Zeni & Higginson, 2010) which examined the kinematic of the ankle joint during forward walking came also to almost similar conclusions. For example, Meyer et al. (2019) found a familiarisation of the *ankle joint ROM* after 5:23 min of forward walking but not in the *Ankle joint ROM ratio*. This result indicates that if a familiarisation period of 5 min is implemented prior to data collection that would be sufficient to obtain stable kinematics. Additional (Zeni & Higginson, 2010) found no increase in the coefficient of determination (r^2) in the *ankle joint inter-stride variability* after the 5th min of a 9 min forward walking trial on a split-belt treadmill. Concluding the authors stated that in order to obtain accurate kinematic data a familiarisation period of at least 5 min is necessary.

It appears that an earlier and adequate task specific warmup process could reduce the variability of the examined parameters and produce stable kinematics. If other types of warmup like running, hopping or cycling can lead to similar results is subject for future research.

4.7. Familiarisation and habituation

Different definitions were used in order to describe the kinematic and kinetic adaptational process when examining forward motion tasks on a treadmill. Most common are the terms *“familiarisation”* and *“habituation”.* Lavcanska et al. (2005) defined the term *“familiarisation”* as the adaptational process that occurs within a session and for the term *“habituation”* the description by Wall and Charteris (1981) was used, which refers to the required long term adaptation process that is distributed over a longer period of time in order for the subjects to produce consistent and similar results in short sessions.

Depending on the motor task different amounts of repetitions are needed to acquire and stabilise a new skill. For forward walking on a treadmill recent studies determined the time needed for the examined variables is between 0 and 10 minutes (Matsas et al., 2000; Meyer et al., 2019; Taylor et al., 1996; Van de Putte et al., 2006). The familiarisation and further habituation process is even more accelerated when two training sessions are conducted per week over a period of 15 weeks (Wall & Charteris, 1981). As a consequence a possible follow up study could be conducted on backward walking habituation on a treadmill similarly to the one performed about forward walking by Wall & Charteris (1981).

5. Limitations

Every study has its limitations and the present research project cannot be excluded. In particular, the determination of the gait events could impose a limitation of the present study. Commonly used methods to determine touch-down and take-off are pressure sensitive insoles or instrumental treadmills with integrated force plates (Matsas et al., 2000; Van de Putte et al., 2006). The pressure sensitive insoles used in the present study unfortunately showed problematic captured data. Therefore, a different methodological approach was used based on the available kinematic data. Although it was used in the past (Zeni et al. 2008, Mayer et al. 2019) it has to be validated and the measuring error assessed with the use of other measuring systems such as: force plates, other pressure insoles or high speed cameras. This could help us determine the presence of a systematic error, its magnitude and to present results that are more accurate.

Another limitation of this study is the absence of the swing phase in the analysed data. We chose to focus only on the stance phase since this approach was implemented in the past by Matsas et al. (2000). Others (Van de Putte et al. 2006; Meyer et al. 2019) did include also the swing phase while examining the kinematic characteristics of the lower body during forward walking. It can be argued that since the swing phase is part of the gait cycle, it should be included in studies when investigating the familiarisation and habituation process. On the other side it can be also argued that the propulsion of the human body is achieved only during the contact time therefore the stance time would have more valuable information for the gait research.

Another possible limitation of this study could be the methodological approach implemented in this study. It is common in the research community (Matsas et al., 2000; Van de Putte et al., 2006; Wass et al., 2005; Zeni & Higginson, 2010) to use discrete points in order to assess the familiarisation of treadmill walking or to make spatio-temporal comparisons between treadmill and over-ground walking. Although these approaches are useful, they take only one point into account and thus the overall movement characteristic during the whole gait cycle cannot by assessed. Therefore, we applied the Procrustes Analyses method (Decker et al. 2007) in order to compare different time series (curve paths) and to gain more information about the whole joint kinematics. This method is delivering a single value range from 0-1 which represents the similarity between curve shapes. Although significant differences were found we are not able to identify the exact points where those differences occurred. This limitation can be overcome with the Statistical Parametric Mapping method. With this alternative approach it could be possible not only to determine differences of gait patterns but also distinguish where and when these occur (Hughes-Oliver et al., 2019).

Another possible limitation of this study would be the determination of the movement speed during the treadmill walking since it was demonstrated that speed has a significant impact on the kinematic results (Stoquart et al., 2008). As previously described (chapter 2.5.) many different methods exist to determine the individual comfortable walking speed which led to varying results. For example the average individual comfortable forward walking speeds were 5km/h (Matsas et al., 2000) 4.59km/h (Zeni & Higginson, 2010) 4.30km/h (Meyer et al., 2019) 4.14km/h (Van de Putte et al., 2006) and 4km/h (Wass et al., 2005). These variations in the horizontal speed could impose higher inter-subject variability in the examined kinematic parameters (Moretto et al., 2007). Therefore, Moretto et al. (2007) proposed the determination of the movement speed by means of the dimensionless Froude Number based on the subject’s leg length and gravity. Reduced kinematic variability is necessary in controlled gait studies where an examined pathology (independent factor) is expected to be highly affected by the chosen walking speed (Wagenaar & Beek, 1992). In our study, we did not examine the effect of spatiotemporal parameter alteration on an independent factor (e.g. pathological) and therefore it was not necessary to implement the aforementioned method.

The warmup time given to the subjects prior the data collection could also be a possible limitation. It was demonstrated that studies about forward walking familiarisation often start the data collection immediately and this can be explained since walking forward is an everyday task (Matsas et al., 2000; Meyer et al., 2019; Taylor et al., 1996; Van de Putte et al., 2006; Wass et al., 2005; Zeni & Higginson, 2010,). On the contrary backward walking is an unusual form of human locomotion therefore it would be problematic to immediately start the testing process on the treadmill without any form of specific (backward walking) warmup process. Therefore, the 5 min specific warmup was necessary to avoid any disturbances (perturbations) during the data collection. Nonetheless, it appears that in forward as well as in backward walking studies the short-term adaption (familiarisation) occurs after 5 minutes of walking irrespective of prior warmup. In the present study it is unclear if a nonspecific warmup routine (forward walking, cycling) would have the same effect as the one implemented. This could be a research subject for future studies.

6. Conclusion

The main finding of this study is that familiarisation of discrete kinematic parameters during 12 min backward walking on a treadmill can be achieved in general after 5-10 minutes of acclimatisation. For the 98 of the 102 examined kinematic and temporal parameters no form of familiarisation during backward walking on a treadmill was found. On the contrary the curve path analysis (Procrustes method) showed significant differences between instances for the *hip angle at fixed walking speed* and *the knee angle at voluntary walking speed* and indicates a familiarisation process. Further analysis with additional methods (Statistical Paramatric Mapping) could probably identify the regions in the curve path of the kinematic variables that exhibit differences.

7. References

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8. Appendix

8.1. Results

In table 6 the results of the *minimum ankle angle* at fixed and voluntary speed over 12 trials of all, male and female participants are depicted. No statistically significant effect of time on the dependent parameter was found.

Table 6: The mean values and standard deviation for the minimum ankle joint angle are shown over 12 minutes. These values are depicted for all, male (n=12) and female (n=12) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). (p>0.05)

Min_AA	**FIXED**			**Voluntary**		
Trial	**Overall [°]**	**Male [°]**	**Female [°]**	**Overall [°]**	**Male [°]**	**Female [°]**
1	77.93 ± 4.38	78.63 ± 5.01	76.86 ± 3.22	78.54 ± 4.67	79.22 ± 5.68	77.51 ± 2.55
2	78.34 ± 4.13	79.00 ± 4.68	77.35 ± 3.14	77.94 ± 4.59	78.70 ± 5.32	76.79 ± 3.19
3	78.48 ± 4.43	79.35 ± 5.07	77.18 ± 3.13	77.94 ± 4.36	78.87 ± 5.07	76.53 ± 2.71
4	78.10 ± 4.40	78.94 ± 4.73	76.84 ± 3.81	78.22 ± 4.17	78.81 ± 5.00	77.34 ± 2.54
5	78.52 ± 4.85	79.57 ± 5.70	76.94 ± 2.85	78.32 ± 4.21	79.27 ± 4.81	76.89 ± 2.80
6	78.33 ± 4.40	79.16 ± 4.74	77.08 ± 3.79	78.18 ± 4.57	79.08 ± 5.34	76.83 ± 2.90
7	78.34 ± 4.60	79.34 ± 4.90	76.84 ± 3.93	77.85 ± 4.93	78.50 ± 6.00	76.87 ± 2.73
8	78.33 ± 4.65	79.17 ± 5.05	77.06 ± 3.93	78.02 ± 4.24	78.51 ± 5.33	77.28 ± 1.76
9	78.18 ± 4.60	79.01 ± 5.23	76.94 ± 3.42	77.97 ± 4.52	78.67 ± 5.36	76.93 ± 2.88
10	78.32 ± 4.49	79.24 ± 5.27	76.93 ± 2.72	77.84 ± 4.14	78.73 ± 4.89	76.50 ± 2.37
11	78.51 ± 4.51	79.47 ± 4.83	77.07 ± 3.82	77.71 ± 4.44	78.72 ± 5.13	76.20 ± 2.78
12	78.33 ± 4.33	78.98 ± 5.14	77.35 ± 2.73	77.89 ± 4.68	78.74 ± 5.55	76.62 ± 2.81

In table the results of the *maximum ankle joint angle* at fixed and voluntary speed over 12 trials of all, male and female participants are depicted. No statistically significant effect of time on the dependent variable could be found.

Table 7: The mean values and standard deviation for the maximum ankle joint angle are shown over 12 minutes. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). (p>0.05)

Max_AA	FIXED			Voluntary		
Trial	**Overall [°]**	**Male [°]**	**Female [°]**	**Overall [°]**	**Male [°]**	**Female [°]**
1	98.09 ± 4.66	98.97 ± 5.08	96.76 ± 3.88	98.43 ± 5.72	98.78 ± 4.92	97.90 ± 7.09
2	98.28 ± 4.49	99.47 ± 3.91	96.50 ± 4.96	98.43 ± 5.71	98.91 ± 4.70	97.70 ± 7.27
3	98.48 ± 5.21	99.27 ± 4.15	97.29 ± 6.63	98.54 ± 5.56	99.30 ± 4.47	97.41 ± 7.08
4	98.55 ± 5.12	99.46 ± 3.58	97.19 ± 6.89	98.75 ± 5.65	99.50 ± 4.95	97.63 ± 6.78
5	98.98 ± 5.56	99.98 ± 4.63	97.48 ± 6.77	98.50 ± 6.07	99.08 ± 4.69	97.63 ± 7.99
6	98.96 ± 6.20	99.54 ± 4.38	98.09 ± 8.53	98.73 ± 5.82	99.07 ± 5.26	98.23 ± 6.92
7	99.16 ± 5.56	100.18 ± 4.33	97.63 ± 7.07	99.15 ± 6.12	99.38 ± 5.29	98.80 ± 7.59
8	98.54 ± 5.41	99.75 ± 4.21	96.72 ± 6.73	98.81 ± 5.16	98.99 ± 4.42	98.53 ± 6.44
9	98.46 ± 5.57	99.19 ± 4.18	97.38 ± 7.39	98.92 ± 5.53	99.29 ± 4.83	98.36 ± 6.78
10	98.55 ± 5.57	99.72 ± 4.63	96.80 ± 6.68	98.63 ± 5.61	98.89 ± 4.62	98.24 ± 7.17
11	98.74 ± 5.48	99.86 ± 4.21	97.05 ± 6.95	98.93 ± 5.42	99.21 ± 4.37	98.51 ± 7.02
12	98.76 ± 5.65	100.12 ± 4.39	96.72 ± 6.95	98.80 ± 5.37	99.19 ± 4.72	98.21 ± 6.52

In table 8 the results of the *ankle joint angle at touch-down* at fixed and voluntary speed over 12 trials of all, male and female participants are depicted. No statistically significant effect of time on the dependent variable could be found.

Table 8: The mean values and standard deviation for the ankle joint angle at touch-down are shown over 12 minutes. These values are depicted for all, male (n=8) and female (n=12) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). (p>0.05)

TD_AA	FIXED			Voluntary		
Trial	**Overall [°]**	**Male [°]**	**Female [°]**	**Overall [°]**	**Male [°]**	**Female [°]**
1	79.51 ± 3.81	80.26 ± 4.39	78.38 ± 2.57	79.68 ± 4.60	80.14 ± 5.43	78.99 ± 3.17
2	79.99 ± 3.61	80.37 ± 4.02	79.43 ± 3.07	79.26 ± 4.57	79.99 ± 5.11	78.16 ± 3.64
3	79.79 ± 4.22	80.44 ± 4.79	78.81 ± 3.24	79.20 ± 4.22	80.00 ± 4.90	78.00 ± 2.80
4	79.48 ± 4.22	80.20 ± 4.33	78.40 ± 4.07	79.53 ± 3.71	80.14 ± 4.17	78.61 ± 2.89
5	79.59 ± 4.57	80.59 ± 5.44	78.10 ± 2.43	79.51 ± 4.06	80.56 ± 4.28	77.95 ± 3.35
6	79.53 ± 4.03	80.16 ± 4.42	78.60 ± 3.43	79.42 ± 4.27	80.37 ± 4.85	78.00 ± 2.96
7	79.50 ± 4.41	80.39 ± 4.60	78.18 ± 4.02	79.16 ± 4.56	79.66 ± 5.26	78.43 ± 3.43
8	79.89 ± 4.23	80.51 ± 4.84	78.96 ± 3.17	79.42 ± 3.86	79.69 ± 4.66	79.01 ± 2.43
9	79.29 ± 4.18	80.16 ± 4.71	77.98 ± 3.07	79.32 ± 4.34	79.93 ± 4.95	78.40 ± 3.32
10	79.74 ± 4.28	80.65 ± 4.95	78.38 ± 2.79	79.03 ± 4.07	79.83 ± 4.67	77.84 ± 2.82
11	80.08 ± 4.15	80.78 ± 4.51	79.04 ± 3.55	79.13 ± 4.09	80.03 ± 4.72	77.79 ± 2.64
12	79.59 ± 4.24	80.28 ± 4.88	78.55 ± 3.05	79.10 ± 4.28	79.85 ± 4.85	77.99 ± 3.23

In table 9 the results of the *ankle joint angle at take-off* at fixed and voluntary speed over 12 trials of all, male and female participants are depicted. No statistically significant effect of time on the dependent variable could be found.

Table 9: The mean values and standard deviation for the ankle joint angle at take-off are shown over 12 minutes. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). (p>0.05)

TOff_AA	**FIXED**			**Voluntary**		
Trial	**Overall [°]**	**Male [°]**	**Female [°]**	**Overall [°]**	**Male [°]**	**Female [°]**
1	90.66 ± 5.01	91.36 ± 5.74	89.59 ± 3.78	91.59 ± 6.39	91.48 ± 4.62	91.76 ± 8.79
2	90.76 ± 4.83	91.50 ± 4.05	89.65 ± 5.94	91.03 ± 6.45	90.97 ± 5.09	91.13 ± 8.49
3	91.37 ± 5.74	91.56 ± 4.13	91.07 ± 7.91	91.03 ± 6.32	91.06 ± 4.61	91.00 ± 8.66
4	90.84 ± 5.90	91.17 ± 3.65	90.34 ± 8.55	91.39 ± 6.45	91.59 ± 4.97	91.11 ± 8.61
5	91.45 ± 5.95	91.94 ± 4.68	90.70 ± 7.79	91.13 ± 6.63	91.27 ± 4.92	90.93 ± 9.00
6	91.39 ± 6.90	91.00 ± 4.47	91.96 ± 9.85	91.27 ± 7.03	91.09 ± 6.25	91.52 ± 8.54
7	91.35 ± 6.42	91.61 ± 4.80	90.96 ± 8.68	91.61 ± 7.07	91.28 ± 6.01	92.10 ± 8.86
8	91.15 ± 6.43	91.86 ± 5.30	90.09 ± 8.13	91.40 ± 5.84	90.94 ± 4.54	92.09 ± 7.70
9	91.10 ± 6.37	91.46 ± 4.39	90.55 ± 8.90	91.24 ± 5.96	90.93 ± 5.04	91.71 ± 7.48
10	91.08 ± 6.22	91.34 ± 4.77	90.70 ± 8.31	91.64 ± 6.20	91.42 ± 4.99	91.95 ± 8.07
11	91.09 ± 6.22	91.44 ± 4.39	90.57 ± 8.61	91.18 ± 6.44	90.70 ± 5.28	91.90 ± 8.24
12	91.25 ± 6.35	91.77 ± 5.05	90.47 ± 8.26	91.09 ± 6.17	90.98 ± 4.99	91.24 ± 8.00

In table 10 the results of the *minimum hip joint angle* at fixed and voluntary speed over 12 trials of all, male and female participants are depicted. No statistically significant effect of time on the dependent variable could be determined.

Table 10: The mean values and standard deviation for the minimum hip joint angle are shown over 12 minutes. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). (p>0.05)

Min_HA	**FIXED**			**Voluntary**		
Trial	**Overall [°]**	**Male [°]**	**Female [°]**	**Overall [°]**	**Male [°]**	**Female [°]**
1	151.14 ± 3.21	150.96 ± 3.44	151.42 ± 3.04	150.49 ± 3.80	150.10 ± 4.10	151.07 ± 3.50
2	150.60 ± 3.80	150.59 ± 4.48	150.61 ± 2.76	150.87 ± 3.77	150.68 ± 4.45	151.17 ± 2.69
3	150.99 ± 3.91	151.06 ± 4.54	150.89 ± 3.01	151.04 ± 3.53	151.17 ± 3.93	150.84 ± 3.08
4	150.75 ± 3.53	151.17 ± 3.75	150.13 ± 3.33	150.85 ± 3.83	151.06 ± 4.25	150.54 ± 3.37
5	150.49 ± 3.48	150.55 ± 4.22	150.41 ± 2.21	150.95 ± 3.98	151.40 ± 4.53	150.28 ± 3.14
6	150.70 ± 3.95	150.66 ± 4.53	150.75 ± 3.16	150.91 ± 3.96	151.08 ± 4.41	150.65 ± 3.44
7	150.69 ± 3.84	150.60 ± 4.29	150.83 ± 3.33	151.29 ± 4.03	151.58 ± 4.78	150.85 ± 2.78
8	150.73 ± 3.53	150.84 ± 4.07	150.57 ± 2.78	150.82 ± 3.83	150.66 ± 4.43	151.07 ± 2.98
9	150.69 ± 3.84	150.99 ± 4.72	150.23 ± 2.15	150.90 ± 4.18	150.97 ± 4.82	150.79 ± 3.31
10	150.45 ± 4.33	150.07 ± 5.09	151.03 ± 3.08	150.79 ± 4.35	151.12 ± 4.80	150.29 ± 3.81
11	150.53 ± 3.64	150.63 ± 4.26	150.38 ± 2.72	150.15 ± 4.02	150.14 ± 4.49	150.16 ± 3.48
12	151.06 ± 3.45	151.06 ± 4.17	151.06 ± 2.25	150.33 ± 4.05	150.52 ± 4.72	150.04 ± 3.06

In table 11 the results of the *maximum hip joint angle* at fixed and voluntary speed over 12 trials of all, male and female participants are depicted. No statistically significant effect of time on the dependent variable could be determined.

Table 11: The mean values and standard deviation for the maximum hip joint angle are shown over 12 minutes. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). (p>0.05)

Max_HA	**FIXED**			**Voluntary**		
Trial	**Overall [°]**	**Male [°]**	**Female [°]**	**Overall [°]**	**Male [°]**	**Female [°]**
1	175.51 ± 5.05	176.06 ± 4.98	174.68 ± 5.37	175.54 ± 4.99	175.67 ± 5.90	175.36 ± 3.59
2	176.50 ± 5.46	176.73 ± 5.76	176.17 ± 5.36	175.77 ± 4.41	176.11 ± 4.44	175.27 ± 4.62
3	176.16 ± 5.34	176.13 ± 5.55	176.20 ± 5.40	175.87 ± 4.70	176.37 ± 5.14	175.13 ± 4.16
4	176.17 ± 5.56	176.24 ± 5.23	176.07 ± 6.39	176.89 ± 5.09	177.40 ± 5.48	176.14 ± 4.69
5	176.40 ± 5.54	176.72 ± 6.44	175.93 ± 4.19	175.99 ± 5.91	176.52 ± 6.12	175.19 ± 5.88
6	175.71 ± 5.96	175.80 ± 6.74	175.56 ± 4.99	176.24 ± 6.56	176.65 ± 7.34	175.61 ± 5.61
7	175.70 ± 6.68	175.14 ± 7.77	176.55 ± 4.98	175.50 ± 6.28	176.09 ± 6.45	174.63 ± 6.33
8	175.80 ± 5.77	175.49 ± 5.92	176.28 ± 5.91	175.44 ± 5.08	175.25 ± 5.29	175.73 ± 5.08
9	175.64 ± 5.68	175.73 ± 6.27	175.49 ± 5.08	175.54 ± 5.66	176.22 ± 6.33	174.53 ± 4.71
10	175.62 ± 6.17	175.39 ± 6.85	175.96 ± 5.41	176.13 ± 6.12	176.65 ± 6.76	175.34 ± 5.36
11	176.04 ± 5.59	175.94 ± 6.20	176.21 ± 4.95	175.91 ± 5.37	176.30 ± 5.23	175.33 ± 5.90
12	175.59 ± 4.81	175.18 ± 5.35	176.21 ± 4.13	175.85 ± 6.19	176.46 ± 6.67	174.95 ± 5.70

In table 12 the results of the *hip joint angle at touch-down* at fixed and voluntary speed over 12 trials of all, male and female participants are depicted. No statistically significant effect of time on the dependent variable could be determined.

Table 12: The mean values and standard deviation for the hip joint angle at touch-down are shown over 12 minutes. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). (p>0.05)

TD_HA	**FIXED**			**Voluntary**		
Trial	**Overall [°]**	**Male [°]**	**Female [°]**	**Overall [°]**	**Male [°]**	**Female [°]**
1	175.35 ± 5.01	175.82 ± 4.95	174.66 ± 5.36	175.47 ± 4.94	175.59 ± 5.83	175.29 ± 3.56
2	176.39 ± 5.47	176.64 ± 5.80	176.00 ± 5.29	175.66 ± 4.34	176.06 ± 4.44	175.06 ± 4.42
3	175.99 ± 5.25	176.07 ± 5.51	175.88 ± 5.21	175.63 ± 4.45	176.15 ± 4.91	174.85 ± 3.83
4	176.10 ± 5.59	176.14 ± 5.29	176.04 ± 6.39	176.76 ± 5.08	177.28 ± 5.56	175.97 ± 4.52
5	176.27 ± 5.38	176.55 ± 6.24	175.85 ± 4.10	175.75 ± 5.61	176.26 ± 5.73	174.97 ± 5.71
6	175.61 ± 5.89	175.72 ± 6.67	175.43 ± 4.90	176.10 ± 6.45	176.57 ± 7.27	175.40 ± 5.38
7	175.63 ± 6.63	175.11 ± 7.75	176.42 ± 4.88	175.37 ± 6.20	176.05 ± 6.42	174.36 ± 6.12
8	175.52 ± 5.51	175.37 ± 5.83	175.73 ± 5.37	175.24 ± 5.09	175.20 ± 5.27	175.30 ± 5.17
9	175.33 ± 5.49	175.61 ± 6.18	174.90 ± 4.61	175.46 ± 5.61	176.13 ± 6.25	174.44 ± 4.69
10	175.46 ± 6.10	175.29 ± 6.82	175.70 ± 5.26	175.81 ± 6.03	176.53 ± 6.75	174.73 ± 4.99
11	175.90 ± 5.50	175.83 ± 6.18	176.00 ± 4.71	175.78 ± 5.33	176.25 ± 5.21	175.08 ± 5.79
12	175.46 ± 4.79	175.07 ± 5.37	176.05 ± 4.04	175.62 ± 6.10	176.27 ± 6.65	174.64 ± 5.45

In table 13 the results of the *hip joint angle at take-off* at fixed and voluntary speed over 12 trials of all, male and female participants are depicted. No statistically significant effect of time on the dependent variable could be determined.

Table 13: The mean values and standard deviation for the hip joint angle at take-off are shown over 12 minutes. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). (p>0.05)

TOff_HA	FIXED			Voluntary		
Trial	**Overall [°]**	**Male [°]**	**Female [°]**	**Overall [°]**	**Male [°]**	**Female [°]**
1	151.14 ± 3.21	150.96 ± 3.44	151.42 ± 3.04	150.49 ± 3.79	150.11 ± 4.09	151.07 ± 3.50
2	150.60 ± 3.80	150.59 ± 4.48	150.61 ± 2.76	150.87 ± 3.77	150.68 ± 4.45	151.17 ± 2.69
3	150.99 ± 3.91	151.06 ± 4.54	150.89 ± 3.01	151.04 ± 3.53	151.17 ± 3.93	150.84 ± 3.08
4	150.79 ± 3.55	151.24 ± 3.76	150.13 ± 3.33	150.85 ± 3.83	151.06 ± 4.25	150.54 ± 3.37
5	150.53 ± 3.49	150.61 ± 4.23	150.41 ± 2.21	150.95 ± 3.98	151.40 ± 4.53	150.28 ± 3.14
6	150.70 ± 3.95	150.66 ± 4.53	150.75 ± 3.16	150.91 ± 3.96	151.08 ± 4.41	150.65 ± 3.44
7	150.70 ± 3.84	150.61 ± 4.29	150.83 ± 3.33	151.29 ± 4.03	151.58 ± 4.78	150.85 ± 2.78
8	150.73 ± 3.53	150.84 ± 4.07	150.57 ± 2.78	150.82 ± 3.83	150.66 ± 4.43	151.07 ± 2.98
9	150.69 ± 3.84	150.99 ± 4.72	150.23 ± 2.15	150.90 ± 4.18	150.97 ± 4.82	150.79 ± 3.31
10	150.45 ± 4.33	150.07 ± 5.09	151.03 ± 3.08	150.79 ± 4.35	151.12 ± 4.80	150.29 ± 3.81
11	150.53 ± 3.64	150.63 ± 4.26	150.38 ± 2.72	150.15 ± 4.02	150.14 ± 4.49	150.16 ± 3.48
12	151.06 ± 3.45	151.06 ± 4.17	151.06 ± 2.25	150.33 ± 4.05	150.52 ± 4.72	150.04 ± 3.06

In table 14 the results of the *minimum knee joint angle* at fixed and voluntary speed over 12 trials of all, male and female participants are depicted. No statistically significant effect of time on the dependent variable could be found.

Table 14: The mean values and standard deviation for the minimum knee joint angle are shown over 12 minutes. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). (p>0.05)

Min_KA	FIXED			Voluntary		
Trial	**Overall [°]**	**Male [°]**	**Female [°]**	**Overall [°]**	**Male [°]**	**Female [°]**
1	155.75 ± 4.92	156.24 ± 5.65	155.03 ± 3.81	155.83 ± 5.32	156.92 ± 6.27	154.18 ± 3.15
2	156.01 ± 5.68	157.15 ± 6.31	154.31 ± 4.42	155.13 ± 4.73	156.20 ± 5.49	153.52 ± 2.92
3	155.78 ± 5.17	156.92 ± 5.61	154.06 ± 4.19	155.38 ± 4.26	156.24 ± 4.53	154.10 ± 3.71
4	156.14 ± 4.89	156.56 ± 5.32	155.51 ± 4.44	155.81 ± 5.51	156.99 ± 6.32	154.05 ± 3.72
5	156.24 ± 4.99	156.46 ± 5.69	155.91 ± 4.07	155.33 ± 5.40	156.45 ± 5.68	153.65 ± 4.81
6	155.57 ± 4.85	156.42 ± 5.42	154.31 ± 3.84	155.11 ± 5.30	156.00 ± 5.99	153.79 ± 4.05
7	156.39 ± 5.51	156.71 ± 6.66	155.91 ± 3.51	154.86 ± 5.83	156.10 ± 6.43	153.02 ± 4.58
8	155.16 ± 5.08	156.02 ± 5.85	153.87 ± 3.61	154.46 ± 5.66	156.04 ± 6.21	152.10 ± 3.97
9	155.39 ± 5.18	155.94 ± 6.28	154.56 ± 3.07	154.31 ± 4.81	155.38 ± 5.64	152.70 ± 2.83
10	154.88 ± 4.68	155.39 ± 5.74	154.10 ± 2.56	155.31 ± 5.29	156.68 ± 5.90	153.27 ± 3.65
11	155.08 ± 4.95	155.92 ± 5.64	153.81 ± 3.68	154.36 ± 5.07	155.50 ± 5.16	152.64 ± 4.71
12	154.67 ± 4.15	154.82 ± 5.02	154.45 ± 2.64	154.78 ± 5.23	155.92 ± 6.19	153.08 ± 2.93

In table 15 the results of the *maximum knee joint angle* at fixed and voluntary speed over 12 trials for all, male and female participants are depicted. No significant effect of time on the dependent variable could be determined.

Table 15: The mean values and standard deviation for the maximum knee joint angle are shown over 12 minutes. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). (p>0.05)

Max_KA	**FIXED**			**Voluntary**		
Trial	**Overall [°]**	**Male [°]**	**Female [°]**	**Overall [°]**	**Male [°]**	**Female [°]**
1	176.62 ± 4.00	177.23 ± 2.98	175.71 ± 5.29	176.30 ± 4.45	176.73 ± 4.27	175.65 ± 4.93
2	176.30 ± 4.49	176.78 ± 3.81	175.59 ± 5.57	176.32 ± 3.79	176.70 ± 3.93	175.76 ± 3.75
3	175.93 ± 4.71	176.48 ± 3.68	175.10 ± 6.12	176.94 ± 3.76	177.48 ± 3.05	176.14 ± 4.75
4	176.63 ± 4.58	177.49 ± 2.84	175.34 ± 6.41	176.38 ± 4.11	177.07 ± 2.72	175.35 ± 5.67
5	176.51 ± 4.28	177.34 ± 3.01	175.26 ± 5.69	176.89 ± 3.88	177.46 ± 2.57	176.03 ± 5.40
6	176.68 ± 4.08	177.28 ± 3.29	175.78 ± 5.17	177.23 ± 4.35	177.73 ± 3.44	176.50 ± 5.62
7	176.76 ± 4.43	177.66 ± 2.76	175.42 ± 6.16	177.33 ± 3.65	177.76 ± 2.73	176.69 ± 4.86
8	176.79 ± 4.66	177.66 ± 2.84	175.49 ± 6.56	176.90 ± 3.74	177.37 ± 3.52	176.21 ± 4.18
9	176.74 ± 4.46	177.19 ± 3.97	176.05 ± 5.31	177.10 ± 4.43	177.80 ± 2.90	176.04 ± 6.17
10	176.29 ± 4.46	177.08 ± 2.94	175.11 ± 6.15	176.72 ± 3.65	177.31 ± 3.06	175.84 ± 4.47
11	176.90 ± 4.61	177.97 ± 2.86	175.31 ± 6.32	176.70 ± 4.30	177.04 ± 3.57	176.21 ± 5.44
12	176.33 ± 4.67	177.16 ± 3.10	175.08 ± 6.41	176.87 ± 4.27	177.44 ± 3.40	176.00 ± 5.48

In table 16 the results for the analysis of the *knee joint angle at take-off* at fixed and voluntary speed over 12 trials of the whole, male and female population are depicted. No statistically significant effect of time on the dependent variable could be determined.

Table 16: The mean values and standard deviation for the knee joint angle at take-off are shown over 12 minutes. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). (p>0.05)

TOff_KA	**FIXED**			**Voluntary**		
Trial	**Overall [°]**	**Male [°]**	**Female [°]**	**Overall [°]**	**Male [°]**	**Female [°]**
1	174.65 ± 4.37	176.08 ± 3.68	172.50 ± 4.67	174.50 ± 4.89	175.48 ± 5.04	173.01 ± 4.57
2	173.87 ± 4.91	175.13 ± 4.92	171.97 ± 4.53	174.42 ± 4.31	175.28 ± 5.08	173.12 ± 2.56
3	173.35 ± 5.35	174.47 ± 5.15	171.68 ± 5.54	174.87 ± 4.53	175.92 ± 4.44	173.29 ± 4.47
4	174.18 ± 5.20	175.75 ± 4.27	171.83 ± 5.84	174.07 ± 4.56	175.11 ± 4.12	172.52 ± 5.02
5	173.92 ± 5.17	175.28 ± 5.10	171.88 ± 4.88	174.97 ± 4.25	176.09 ± 3.89	173.28 ± 4.45
6	174.39 ± 4.52	175.48 ± 4.73	172.77 ± 3.92	175.36 ± 4.57	176.40 ± 4.04	173.80 ± 5.14
7	174.24 ± 5.15	175.69 ± 4.78	172.08 ± 5.21	175.09 ± 3.91	175.90 ± 3.95	173.89 ± 3.77
8	174.39 ± 5.40	175.99 ± 4.40	171.98 ± 6.13	174.89 ± 4.68	175.74 ± 5.16	173.61 ± 3.82
9	174.23 ± 4.96	175.12 ± 5.47	172.89 ± 4.04	174.99 ± 5.01	176.10 ± 4.76	173.33 ± 5.21
10	173.77 ± 4.81	175.12 ± 4.38	171.74 ± 4.99	174.38 ± 4.48	175.28 ± 4.70	173.02 ± 4.02
11	174.13 ± 5.27	175.23 ± 4.97	172.49 ± 5.60	174.44 ± 4.79	175.24 ± 4.96	173.24 ± 4.58
12	173.89 ± 5.35	175.45 ± 4.66	171.54 ± 5.74	174.82 ± 4.79	176.09 ± 4.69	172.91 ± 4.56

In table 17 the results of the *stride time* at fixed and voluntary speed over 12 trials of all, male and female participants are depicted. No statistically significant effect of time on the dependent variable could be determined.

Table 17: The mean values and standard deviation for the stride time are shown over 12 minutes. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). (p>0.05)

Stride	**FIXED**			**Voluntary**		
Trial	**Overall [s]**	**Male [s]**	**Female [s]**	**Overall [s]**	**Male [s]**	**Female [s]**
1	1.20 ± 0.11	1.21 ± 0.10	1.17 ± 0.12	1.20 ± 0.10	1.21 ± 0.09	1.19 ± 0.10
2	1.23 ± 0.12	1.26 ± 0.13	1.18 ± 0.10	1.20 ± 0.12	1.22 ± 0.10	1.17 ± 0.13
3	1.22 ± 0.11	1.24 ± 0.10	1.19 ± 0.13	1.20 ± 0.09	1.21 ± 0.09	1.19 ± 0.09
4	1.24 ± 0.13	1.26 ± 0.14	1.21 ± 0.11	1.20 ± 0.10	1.20 ± 0.11	1.19 ± 0.09
5	1.24 ± 0.13	1.29 ± 0.13	1.17 ± 0.10	1.20 ± 0.09	1.20 ± 0.08	1.22 ± 0.11
6	1.23 ± 0.12	1.27 ± 0.11	1.18 ± 0.12	1.21 ± 0.10	1.21 ± 0.10	1.21 ± 0.11
7	1.23 ± 0.11	1.26 ± 0.11	1.20 ± 0.10	1.21 ± 0.12	1.21 ± 0.11	1.23 ± 0.14
8	1.24 ± 0.10	1.26 ± 0.10	1.20 ± 0.10	1.23 ± 0.14	1.22 ± 0.12	1.23 ± 0.16
9	1.23 ± 0.12	1.25 ± 0.13	1.21 ± 0.12	1.22 ± 0.11	1.22 ± 0.11	1.23 ± 0.12
10	1.21 ± 0.13	1.24 ± 0.13	1.17 ± 0.12	1.21 ± 0.12	1.20 ± 0.09	1.23 ± 0.16
11	1.24 ± 0.13	1.26 ± 0.13	1.22 ± 0.13	1.23 ± 0.12	1.22 ± 0.09	1.26 ± 0.15
12	1.23 ± 0.14	1.26 ± 0.14	1.19 ± 0.13	1.21 ± 0.11	1.21 ± 0.10	1.22 ± 0.13

In table 18 the results of the *Procrustes distances of the ankle angle* at fixed and voluntary speed over 11 paired trials of all, male and female participants are depicted. No statistically significant effect of time on the depended variable could be determined.

Table 18: The mean Procrustes distances / root mean square distances and standard deviation are shown for the ankle joint angle over 11 trials. These values are depicted for all, male (n=12) and female (n=8) participants for the fixed (2.5km/h) and the voluntary speed (2.69±0.37km/h). (p>0.05)

PC_AA	**FIXED**			**Voluntary**		
Trial	**Overall**	**Male**	**Female**	**Overall**	**Male**	**Female**
1	0.023 ± 0.038	0.030 ± 0.048	0.013 ± 0.010	0.014 ± 0.009	0.011 ± 0.007	0.017 ± 0.011
2	0.011 ± 0.010	0.010 ± 0.008	0.013 ± 0.012	0.022 ± 0.022	0.024 ± 0.026	0.020 ± 0.015
3	0.013 ± 0.011	0.011 ± 0.009	0.017 ± 0.014	0.015 ± 0.015	0.015 ± 0.018	0.014 ± 0.010
4	0.015 ± 0.010	0.013 ± 0.008	0.018 ± 0.012	0.026 ± 0.046	0.032 ± 0.059	0.017 ± 0.012
5	0.017 ± 0.014	0.015 ± 0.011	0.020 ± 0.017	0.019 ± 0.019	0.025 ± 0.023	0.010 ± 0.005
6	0.023 ± 0.029	0.030 ± 0.036	0.014 ± 0.013	0.014 ± 0.014	0.014 ± 0.017	0.015 ± 0.008
7	0.022 ± 0.025	0.024 ± 0.031	0.019 ± 0.016	0.022 ± 0.037	0.028 ± 0.046	0.011 ± 0.009
8	0.017 ± 0.015	0.013 ± 0.013	0.025 ± 0.016	0.011 ± 0.011	0.012 ± 0.013	0.009 ± 0.007
9	0.019 ± 0.016	0.017 ± 0.015	0.022 ± 0.017	0.013 ± 0.009	0.013 ± 0.011	0.013 ± 0.007
10	0.012 ± 0.008	0.011 ± 0.008	0.013 ± 0.008	0.013 ± 0.010	0.011 ± 0.010	0.016 ± 0.010
11	0.010 ± 0.008	0.009 ± 0.005	0.010 ± 0.011	0.017 ± 0.017	0.013 ± 0.014	0.022 ± 0.021

8.2. List of Figures

8.3. List of Tables

9. Declaration

„Ich erkläre, dass ich die vorliegende Arbeit selbstständig verfasst und nur die ausgewiesenen Hilfsmittel verwendet habe. Diese Arbeit wurde weder an einer anderen Stelle eingereicht noch von anderen Personen vorgelegt."

Wien, am ________________________ ______________________________

Datum Unterschrift