THE USE OF THE GRADUAL YIELDING MECHANISM DURING DOWNHILL WALKING IN TRANSFEMORAL AMPUTEE GAIT – A CASE STUDY

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To facilitate downhill walking in transfemoral amputees, some prostheses contain knee joints that have a yielding mechanism. The aim of this case study was to investigate 1) at which gradient unilateral transfemoral (UTF) amputees first utilised the yielding mechanism, 2) whether this mechanism is linked to altered spatio-temporal parameters and 3) if the switch occurs at a different gradient when the prosthetic ankle component is altered. Two UTF amputees walked at different slopes (0° to -15°) with an articulating and a rigid prosthetic ankle component. Results showed that the gradient at which the UTFs first used the yielding mechanism is highly individual (UTF1: -6°; UTF2: -12°). UTF2 showed with the switch a decreased speed, step & stride length. The use of an articulating compared to a rigid ankle component did not influence the yielding pattern.

KEY WORDS: prosthesis, amputation, slope.

INTRODUCTION: For lower limb amputees, downhill walking is a complex task due to the reduced proprioceptive feedback from the residual limb and the prosthetic characteristics and constraints that oblige them to adopt compensatory gait mechanisms (Vrieling, van Keeken, Schoppen, Otten, Halbertsma, Hof et al., 2008), leading to an asymmetric gait pattern (Kaufman, Frittoli, & Frigo, 2012; Schaarschmidt, Lipfert, Meier-Gratz, Scholle, & Seyfarth, 2012). Unilateral transfemoral (UTF) amputees cannot actively flex their prosthetic knee, without the use of advanced components. During stance the artificial knee stays in an extended position and the Centre of Mass (CoM) is anterior to the articulating knee joint centre. UTFs modify their gait pattern accordingly during level walking. When the CoM is posterior of the articulating knee joint centre, the knee will flex. Therefore, to prevent an immediate collapse of the artificial knee some knees have a yielding mechanisms, which allows for a controlled flexion of the knee during downhill walking or stair descent (Koganezawa, Fujimoto, & Kato, 1987). Hence, UTF amputees can change their kinematic pattern to voluntarily activate the gradual yielding of the knee joint. Despite this mechanical possibility, it is unclear to which extend UTFs actually apply the yielding mechanism during downhill walking, and if other components of the prosthetic limb, e.g. ankle componentry, influence the use of the yielding mechanism. As example, UTFs use this mechanism during stair descent (Koganezawa et al., 1987), but did not use it at -5% downhill walking (Vrieling et al., 2008). Additionally, it is of interest, if the changes in the movement pattern are also reflected by changes in the spatio-temporal parameters.
Different prosthetic ankle components e.g. rigid vs. articulating ankle joints, influence gait kinematics and might also influence the utilisation of the yielding mechanism. During level walking transtibial and transfemoral amputees showed that, when using a hydraulic vs. rigid ankle component, forward progression of the centre of pressure and minimum toe clearance increased and total work done by the intact limb is reduced, resulting in an increased freely chosen walking speed (De Asha, Johnson, Munjal, Kulkarni, & Buckley, 2013; De Asha, Munjal, Kulkarni, & Buckley, 2014).
Therefore, the aim of the current case study was to 1) analyse the gradient at which two UTF amputees first switch from a walking pattern with a stable extended lower limb to the use of the yielding mechanism, 2) investigate if the use of this mechanism can be linked to changes in the spatio-temporo parameters and 3) investigate if the switch occurs at a different gradient when using a hydraulically articulating compared to a rigid prosthetic ankle component.

METHODS: Two UTF amputees (UTF1: female, 50 years, 1.80 m, 62.3 kg; UTF2: male, 54 years, 1.84 m, 83.0 kg) provided written informed consent to participate in the current study and institutional ethics committee approval was obtained prior to data collection.
In this pilot study both UTF amputees walked overground in level and downhill slope conditions using their habitual prosthetic knee components. Participant UTF1 used the C-Leg (OttoBock Health-Care, Germany) prosthetic knee joint, which uses a hydraulic system with two separate servo valves for the extension and flexion movement (Thiele, Westebbe, Bellmann, & Kraft, 2014). Participant UTF2 used a Milwaukee TF socket (Guenther Bionics GmbH, Germany) and the Orion (Chas A Blatchford & Sons Ltd, UK) prosthetic knee joint, which consists of a combination of a hydraulic and a pneumatic unit (Thiele et al., 2014). Both UTF amputees used the same foot consisting of an e-carbon heel and toe spring. This foot allows for plantar and dorsiflexion (heel & toe spring) as well as for pronation and supination (two-toed leaf spring design). On this foot an articulating (1) and a rigid (2) prosthetic ankle component was consecutively attached: (1) the articulating ankle component (ARTIC) (Model: Elan, Chas A Blatchford & Sons Ltd, UK) uses a hydraulic ankle joint with adaptive resistance during dorsi-flexion and plantar-flexion (-3° to 6°). The ankle joint is equipped with a microprocessor controlled speed and terrain response, which uses a braking mechanism during descending. (2) The rigid ankle component (RIGID) (Model: Esprit, Chas A Blatchford & Sons Ltd, UK) uses a rigid connection between the foot and the shank. The participants were familiarized with both ankle components by using them alternately several months prior to testing. During the study approximately one hour was given to adapt to each ankle component.
An instrumented ramp (6 m x 1.5 m) with two force plates (AMTI, Advanced Mechanical Technology Inc., Watertown, Massachusetts, USA) imbedded in the middle of the walkway was set consecutively to the downhill slopes of -15° (only UTF2), -12°, -8° (only UTF1), -6° and -4° as well as to 0° for level walking.
The force plate data were sampled at 1000 Hz. Kinematic data were recorded with a twelve-camera motion capture system (Vicon, Oxford Metrics Ltd, Oxford, UK) at 250 Hz sampling frequency. Reflective markers were placed on the lower extremities according to the Cleveland Clinic Marker set (Motion Analysis Corp., Santa Rosa, CA, USA). Markers to identify the calibration landmarks on the prosthetic knee were placed medially and laterally of the rotational joint centre of the prosthetic leg. At the prosthetic ankle the calibration landmark were placed medially and laterally of the spring-loaded axle, while the respective foot segment markers were chosen to correspond to those on the intact side. For each condition, five trials at self-selected walking speed were recorded. Kinematic and kinetic data were filtered using a Butterworth filter with 6 Hz cut-off frequency. Mean values of the five trials were calculated for the sagittal knee angle of the residual limb, which was normalized to gait cycle duration. Furthermore, the spatio-temporal parameters speed, stride frequency, stride length, step length and stance time were calculated within Visual 3D (C-Motion Inc., Germantown, USA) as well as the 95% confidence interval for the five trials.

RESULTS: UTF1 switched to the gradual yielding at -6° downhill walking, while UTF2 switched at -12°. For both UTF amputees the switch was independent of prosthetic ankle components (Figure 1). At inclinations when the gradual yielding mechanism was not used, there is no knee flexion until 50% of the gait cycle duration. In contrast, when participants use the yielding mechanism, the knee flexion increases continuously after initial contact and reaches the maximum flexion earlier compared to walking without the gradual yielding (Figure 1). Furthermore, with increasing inclination the knee flexion peak increases and occurs earlier during the gait cycle.

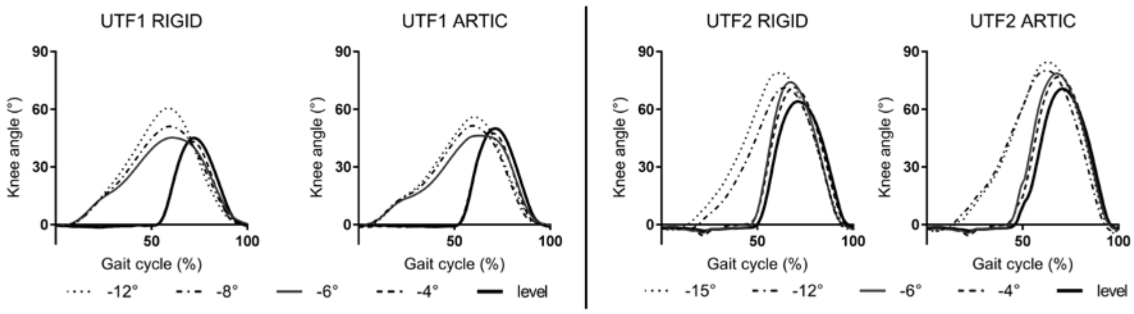

Figure 1: Knee angle during level and downhill walking of UTF1 and UTF2 with RIGID and ARTIC.

At the transition from "normal" to "yielding" gait (-4° to -6°) the differences in spatio-temporal parameters for UTF1 were not greater compared to differences between the other inclination changes. In contrast, for UTF2 noticeable differences in residual step length, stride length and speed occurred at the transition from "normal" to "yielding" gait from 6°-12° for both ankle components: e.g. residual limb step length was similar (ARTIC and RIGID) at level (ARTIC: 0.78 (0.03) m; RIGID: 0.81 (0.01) m), -4° (ARTIC: 0.82 (0.03) m; RIGID: 0.85 (0.02) m) and -6° (ARTIC: 0.82 (0.04) m; RIGID: 0.85 (0.05) m), but decreased by -0.26 m (ARTIC) and -0.37 m (RIGID) from -6° to -12°. It further remained stable from -12° (ARTIC: 0.56 (0.06) m; RIGID: 0.48 (0.05) m) to -15° (ARTIC: 0.48 (0.03) m; RIGID: 0.44 (0.02) m). A comparable pattern occurred for stride length. Speed was also decreased substantially at the transition slope (-6° to -12°; ARTIC: -0.20 m/s; RIGID: -0.43 m/s) and was further decreased at -15° downhill walking when using ARTIC (-0.14 m/s).

DISCUSSION: The first aim of the current case study was to analyse the gradient at which the two UTF amputees first utilized the prosthetic yielding mechanism. It was shown that responses to this downhill slope was highly individual, UTF1 switched to the gradual yielding at -6° downhill walking, while UTF2 started using it at -12° (Figure 1). In general, the use of the gradual yielding mechanism during downhill walking in the current study resulted in a similar knee angle as reported in the literature during stair descent (Koganezawa et al., 1987). Furthermore, with increasing inclination the knee flexion peak increased and occurred earlier during the gait cycle (Figure 1). These effects of downhill walking were also observed in able-bodied downhill gait (Lay, Hass, & Gregor, 2006).

The second aim was to investigate, whether the utilization of the yielding mechanism can be linked to changes in the spatio-temporal parameters. While UTF1 did not shown any changes in spatio-temporal parameters that seem to concur with the utilization of the yielding mechanism, UTF2 showed adaptations at the transition from "normal" to "yielding" gait (-6° to -12°) in step length (residual limb), stride length and speed. It has to be kept in mind that UTF2s transition inclination has the highest absolute difference of 6° between inclinations. However, the residual limb step length was similar at inclinations before and after transition. Furthermore, Lay et al. (2006) have analysed able-bodied participants during downhill walking at -15% (-8.5°) and -39% (-21.3°) as well as level walking and did not show any significant differences in stance duration, stride duration, and stride length normalized to leg length. Therefore, it may be assumed that for UTF2 the use of the gradual yielding mechanism is associated with decreased step length, stride length and speed. The individual differences concerning the spatio-temporal parameters between the two UTF amputees could be caused by different levels of confidence. UTF1 might be more cautious and therefore no abrupt changes in spatio-temporal parameters occur when the gradual yielding mechanism is first used. In contrast, UTF2 might be more confident in the use of the prosthetic devices during "normal" gait, but gets cautious when using the gradual yielding mechanism. This consideration is supported by the slower walking speed and shorter step and stride lengths of UTF1 compared to UTF2 during level walking and lower inclinations.

The third aim was to analyse if different prosthetic ankle components have an influence on the slope when the yielding mechanism is first utilised. While differences during downhill walking in a UTF amputee regarding the residual hip joint moments have been shown when using ARTIC compared to RIGID (Alexander, Strutzenberger, Kroell, Barnett, & Schwameder), no differences between prosthetic ankle components concerning the use of the gradual yielding mechanism were observed in the current study.
Finally, the findings of the current study apply to two individual UTF amputees and generalization to a wider population must be made with caution. The recruitment of several TF amputees, who are all fully adapted to the different prostheses over a long period of time, however, is practically difficult to achieve. Therefore, while acknowledging the limitations, this case study provided useful comparisons without major influences of patient adaptation on the data. Furthermore, it has to be kept in mind that the two UTF amputees used different prosthetic knee devices, which have different characteristics (Thiele et al., 2014).

CONCLUSION: This study identified the inclination when UTF amputees start to use the gradual yielding mechanism and showed that this is highly individual. One of the UTF amputees showed decreased step length, stride length and speed when starting to use the gradual yielding mechanism. This information can be used for the development of task specific prosthesis. Furthermore, the use of a hydraulically articulating compared to a rigid ankle component did not influence the yielding movement pattern during downhill walking.

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