Abstract

Introduction Prosthetic ankle-foot devices incorporating a hydraulic articulation between the pylon and prosthetic foot have been shown to be beneficial to the gait of more active individuals with unilateral transtibial amputation (UTA). However, the functional benefits of using hydraulic ankle-foot devices to less active individuals with UTA are yet to be determined. The aim of the current study was to investigate the effects on gait performance of using a non-ESR foot with a hydraulic attachment, compared to an identical, rigidly attached foot during overground walking in less active individuals with UTA.

Materials and Methods Kinematic and kinetic data were recorded while five individuals with UTA, deemed K2 activity level by their prescribing physician, performed two-minute walk tests (2MWT) and ten overground gait trials, in two conditions; using a hydraulically articulating ankle foot device (HYD) and using a rigidly attached ankle foot device (RIG).

Results Walking speed during the 2MWT was increased by 6.5% on average, in the HYD (1.07 m/s) condition, compared to the RIG (1.01 m/s) condition (Cohen's d = 0.4). Participants displayed more symmetrical inter-limb loading (d = 0.8), increased minimum forward centre of pressure velocity (d = 0.8), increased peak shank rotational velocity (d = 1.0) and decreased prosthetic energy efficiency (d = 0.7) when using the HYD compared to RIG device.

Conclusions Individuals with lower activity levels walk faster and therefore further when, using a foot with a hydraulically articulating attachment, in comparison to a rigid attachment. A reduced braking effect in early stance phase, as a result of the action of the hydraulic component present in the articulating attachment, partially explains the improvement in walking performance.

Keywords Lower-limb amputation, Prosthetics, Foot device, Ankle, hydraulic.

Introduction

Prosthetic ankle-foot devices that incorporate hydraulically damped articulation between the pylon and prosthetic foot are a relatively new development in prosthetic technology, having only been widely commercially available for approximately ten years. Feet such as the Kinterra (Freedom Innovations, Morgan, CA), Echelon (Chas. A Blatchford & Sons, Basingstoke, UK) and MotionFoot (Fillauer, Chattanooga, TN) combine a hydraulic articulation unit with an energy storing and returning (ESR) foot, and are primarily intended for use by individuals with higher levels of mobility, such as those classified as being at least K3 on the Medicare Scale. The hydraulic dashpots present in the articulation mechanism of such prosthetic ankle-foot devices cause the ankle-foot system to absorb more and return less energy during stance than an identical, rigidly attached, foot [1]. In addition, due to the hydraulic component, such ankle-foot devices also weigh more than comparable, rigidly attached, feet.

Despite these apparent drawbacks, it has been reported that hydraulic ankle-foot devices provide functional benefits during walking, when compared to feet that are either attached without articulation, or attached via an elastic articulation device. The primary reported functional benefit, when using a hydraulic ankle-foot device, in more active (K3) individuals with lower limb amputation, is an increase in the individual's walking speed [1-4]. Walking speed is a primary measure of gait function in individuals with lower-limb amputation [5]. Furthermore, for individuals with a lower-limb amputation, an increase in walking speed reflects improved gait function during and following rehabilitation [6-8], and is also associated with decreased temporal asymmetry [9]. This increase in walking speed, when using a hydraulic ankle-foot device, appears to be driven by a reduction in inappropriate fluctuations of centre of pressure progression during prosthetic-limb stance [2], where the centre of pressure becomes stationary or travels backwards beneath the prosthetic hind and/or mid foot [10,11]. In addition to this, hydraulic articulation has been found to result in increased forwards angular velocity of the prosthetic shank during early stance [2]. These effects occur despite the devices' hydraulic dashpots dissipating energy during stance, resulting in reduced energetic efficiency compared to that of a rigidly attached foot [1]. Accordingly, the increased walking speed appears to be due to a reduced 'braking effect' [12], rather than increased propulsion, allowing the transfer of weight onto the prosthetic limb to occur more smoothly [2]. Another effect of using a hydraulic ankle-foot device is a reduction in load-bearing asymmetry during walking [1], that possibly contributes to a reported reduction in in-socket pressures, due to reduced loading rates [13]

The effects of using a hydraulic ankle-foot device have been observed in individuals with both unilateral transtibial (UTA) and transfemoral amputation [14] although, again, only in patients who are described as being at least K3 on the Medicare Mobility Scale. Individuals who are less mobile are seldom prescribed ESR feet, and therefore, rarely use feet with hydraulic 'ankle' function. However, the apparent benefits of using hydraulic ankle-foot devices observed in more mobile individuals may also occur in the less active. This suggestion is supported by a low-activity group self-reporting improvements in their gait and prosthesis satisfaction when their prosthetic prescription was changed to include a hydraulic ankle-foot device [15].

Therefore, the aim of this study was to investigate the effects, of using a non-ESR foot with a hydraulic attachment, during overground walking, compared to an identical, rigidly attached foot, in individuals with UTA, described as being K2 on the Medicare scale. It was hypothesized that, (1) when using the hydraulic ankle-foot device, individuals would walk faster compared to when using an identical, rigidly attached foot device. It was expected that any increase in walking speed would be due to the same drivers previously reported in more active individuals when using a prosthetic ankle-foot device that incorporates a hydraulically articulating attachment. Thus, it was also hypothesized that, (2) there would be an increased minimum forwards/peak backwards velocity of centre of pressure progression beneath the prosthetic foot, increased angular velocity of the prosthetic shank during early stance and a reduction in stance phase load bearing asymmetry between the intact and residual limbs when using the hydraulic compared to rigidly attached ankle-foot device. Finally, it was expected that these effects would occur despite a reduction in efficiency of the ankle-foot device, due to the hydraulic unit dissipating energy during stance.

Methods

Participants

Five individuals with UTA, currently assessed as being K2 on the Medicare scale by their prescribing physician, were recruited from the same prosthetic limb and rehabilitation centre. All provided written informed consent prior to participation in the study, which was approved by the Nottingham Trent University Human Research Ethics Committee (Table 1).

Insert Table 1 here

Participants were recruited and included, if they: 1) were community living adults aged between 18 and 65 years of age; 2) were able to walk without walking aids for periods of at least two minutes; 3) partook in physical activity at least once a week for 30 minutes; 4) had good (corrected, if necessary) vision and 5) had no unresolved health issues, as determined using a health screening questionnaire. Individuals were excluded, if they: 1) had experienced an unintentional fall in the previous 12 months; 2) experienced undue pain while walking; 3) were current smokers or 4) were currently taking five or more prescribed medications.

Experimental Design

Participants were required to complete the below described walking tasks while using the same habitual socket/liner and same non-ESR foot, attached under two different conditions: (1) using a hydraulically articulating attachment (HYD - Avalon^{K2}) and (2) using a rigid non-articulating attachment (RIG - Navigator; both Chas A. Blatchford & Sons, Basingstoke, UK; Figure 1). These feet were chosen as they are identical, save for the nature of attachment to the prosthetic pylon. In order to ameliorate any order effects, the order in which participants completed walking tasks were counterbalanced across participants according to which was their habitual device, regardless of whether this was the RIG or HYD. For each condition participants initially, completed a familiarisation trial followed by a measured trial of the two-minute walk test (2MWT). The 2MWT comprised two 15m straight sections with a 180 degree turn at either end, in order to mitigate the effects of turning on walking test performance [16] [17]. Participants then completed 10 discrete overground walking trials along a 15m instrumented walkway including two force plates. Participants were instructed for all tests to walk as they would normally. The same highly experienced prosthetist made all necessary adjustments to all participants' prostheses, when changing between prosthetic conditions. Other than different ankle-foot device attachment, there was no difference in the prostheses between conditions. Participants were asked to complete the

Activities-specific Balance Confidence Scale (ABC) [18], the Houghton Scale of Prosthetic Use (Houghton) [19] and the Prosthetic Limb Users Survey of Mobility (Plus-M 12) [20] which are self-report questionnaires providing information on participants self-perception of balance confidence, prosthetic use and mobility, respectively. Higher scores on these scales reflect increased balance confidence (ABC), prosthesis use (Houghton) and mobility (Plus-M 12).

Insert Figure 1 here

Experimental Protocol

Participants attended data collection sessions wearing comfortable clothing and their normal everyday shoes. In order to define a seven segment model of the lower limbs (feet, thighs, shanks) and pelvis, reflective markers (14 mm diameter) were affixed bilaterally to participants at the following locations: 1st and 5th distal metatarsal heads, lateral border and anterior aspect of the foot, calcaneus, medial and lateral malleoli and femoral epicondyles and anterior and posterior superior iliac spines. A rigid cluster of four markers was also affixed to the lateral side of each shank segment. Foot markers were placed over the shoes. Marker placement on the residual/prosthetic limb was estimated from anatomical landmarks on the intact limb [6] with the prosthesis being modelled as a unified deformable segment [21]. Participants commenced each 2MWT trial by standing at the end of the walkway and were free to self-select a turning direction. The number of strides taken by each participant during the 2MWT were recorded by an investigator using a hand tally counter and the two-minute walk distance (2MWD) was recorded. Participants then completed the overground walking trials at a self-selected speed, for which start positions were adjusted to ensure a clean contact with the forces platforms without any obvious targeting or adjustment to stride pattern. A nine-camera motion capture system (Oqus 400, Qualisys AB, Gothenburg, SE) and two force plates (OR6-7, AMTI, Watertown, MA, US) recorded kinematic and kinetic data at 100Hz and 500Hz, respectively. A static calibration was performed by collecting kinematic data of each participant standing in the anatomical position. Participants were afforded rest breaks as and when required.

Data Analysis

Each 2MWT trials yielded outcome measures of two-minute walk distance (2MWD), walking speed (m/s), determined by dividing the recorded 2MWD by 120 seconds, and the number of strides (stride count). To obtain other variables, biomechanical data for the 10 overground walking trials were analysed. The raw kinematic data were interpolated using a cubic spline algorithm and both the kinematic and kinetic data were smoothed using a zero-lag Butterworth filter with a 6 Hz cut-off frequency (Visual3D, C-Motion, Germantown, USA). Heel strike and toe off were defined as ascending and descending thresholds of 20 N in the vertical component of the ground reaction force, respectively. The following biomechanical outcome measures were calculated: 1) Load bearing symmetry; defined as the ratio of the peak vertical component of the ground reaction force during intact and prosthetic limb stance, 2) peak shank rotational velocity; defined as the peak angular velocity of the prosthetic shank in the sagittal plane from prosthetic heel strike until intact toe off, 3) minimum centre of pressure (COP) velocity; defined as the minimum forwards or peak backwards (in the direction of travel) velocity of the COP during prosthetic limb stance, and 4) prosthetic energetic efficiency; defined as the ratio of energy absorbed and energy returned by the prosthetic foot device during prosthetic limb stance. Energy absorbed and returned were defined as the positive and negative integrals, respectively, of unified deformable segment power during prosthetic limb stance [21]. For each participant, the outcome variables were calculated for each trial, in each prosthetic condition, and the mean for each condition was computed using the results from each trial. No inferential statistical analyses were made, rather, the results for each participant, in each prosthetic condition are presented. This approach was taken due to participants' reaction to altered prosthetic componentry being an individual response [4] and the small group size. Effect sizes (Cohen's d) were calculated using group mean and standard deviation differences between prosthetic conditions [22]. An effect size ≥ 0.4 was operationally defined as being clinically meaningful in the current study [23].

Results

Two-minute walk test outcome measures

During the 2MWT, participants walked, on average, with a 6.5% increase in self-selected walking speed (d = 0.4, Figure 2), and thus an increased 2MWD (d = 0.4, Table 2), when using the HYD compared to the RIG device. This increase in walking speed and 2MWD using the HYD device was present across all participants. The number of strides taken during the 2MWT also increased using the HYD, when compared to the RIG device in all participants, although not to the same extent as the walking speed, with, on average, a 3.9% increase (d = 0.3, Table 2).

Insert Figure 2 here

Insert Table 2 here

Biomechanical outcome measures

All participants' load bearing was more symmetrical between limbs (d = 0.8, Table 3) when using the HYD compared to RIG device. Similarly, peak shank rotational velocity (d = 1.0, Table

3) increased for all participants except one, and minimum forward COP velocity (d = 0.8, Table 3) increased for all, when using the HYD compared to RIG device. The HYD device tended to absorb more, and return less, energy during stance phase, which resulted in a reduced prosthetic energy efficiency for all participants, when using the HYD device compared to the RIG device (d = 0.7, Table 3).

Discussion

The aim of the current study was to investigate the effects of using a hydraulically articulating ‘ankle’ attachment versus a rigid non-articulating attachment with a non-ESR prosthetic foot, on gait performance during level gait in individuals with UTA, described as being K2 on the Medicare scale by their physician. The first hypothesis, that when using the hydraulic ankle-foot device, individuals would walk faster compared to when using an identical, rigidly attached foot device, was supported. Every participant in the current study walked more quickly, and thus on average 7.8m further, during the 2MWT when using the hydraulic ankle-foot device compared to when using the rigidly attached foot. Additionally, post-hoc analysis indicated that during the 10 discrete trials, participants mean (SD) walking speed was greater using the hydraulic ankle-foot device compared to using the rigidly attached foot (HYD, 1.19 (0.09) m/s, RIG, 1.16 (0.10) m/s). In addition, walking speed was greater in both prosthetic conditions during discrete trials compared to during the 2MWT. This observation of increased walking speeds during discrete trials vs. continuous walking in the current study are consistent with previous reports from healthy individuals [24]. Increases in walking speed have been previously demonstrated in individuals with UTA with higher levels of physical function [1-4]. One cohort study of more active individuals [2] reported a 7% increase (d = 0.5) in self-selected walking speed when using a hydraulic ‘ankle’ device, which is similar to the results of the current study (6.5% increase, d = 0.4). Thus, we feel that, despite the current study being a case-series rather than cohort study, it demonstrates that hydraulic ‘ankle’ function also appears to benefit those defined as having a relatively low level of activity.

Increased walking speed is positively correlated with improved self-efficacy of gait among individuals with lower-limb amputation [25]. Every participant in the current study walked more quickly with the HYD and stated a preference for using the HYD rather than the RIG device. This preference corroborated a previous report of improved user satisfaction when using an Avalon^{K2} ankle-foot device [15]. Following data collection, all were offered whichever ankle-foot device (HYD or RIG) they preferred (if it was not their currently prescribed device), to be provided to their prosthetist for subsequent fitting. Four of the five participants, whose currently prescribed device was the RIG, opted for the HYD. The fifth participant, who used a HYD prior to data collection, retained that device. Anecdotal, but interesting nonetheless, following data collection all participants were asked whether they had felt as if they were walking faster when using one ankle-foot device in particular and all said no. It is well documented that self-selected walking speed is related to minimising energy expenditure (e.g. [26]). Although joint kinetics were not outcome variables in the current study, previously it has been reported that use of a similar HYD, but with an ESR foot, resulted in a reduction in mechanical work per metre travelled at the intact limb in more active individuals [2], which possibly contributed to a significant reduction in metabolic cost due to the function of the HYD [14]. Although no supporting data is presented from the current study it may be postulated that, given the increase in walking speed and lack of awareness of such among participants, use of a HYD device has similar effects in less mobile individuals too. This suggestion should certainly be the subject of future research.

The second hypothesis related to the biomechanical explanation of the predicted increased walking speed associated with the hydraulically articulating ankle-foot device. The hypothesis that there would be an increased minimum forwards/peak backwards COP velocity beneath the prosthetic foot, increased angular velocity of the prosthetic shank during early stance and a reduction in stance phase inter-limb load bearing asymmetry was supported in the majority of participants. These findings were consistent with those previously reported in higher activity individuals with the same level of amputation walking using devices with similar functions [1,2] and go some way in explaining the increases in walking speed observed in the current study. The increased energy absorbed and dissipated, rather than returned, by the hydraulic dashpot present in the HYD may have allowed the individuals to load the residual limb to a greater extent. This was reflected in the increase in inter-limb loading symmetry, without the requirement for this energy to be attenuated by deformation in the remaining proximal biological joints and/or structures e.g. biological knee joint, residuum-socket interface. There are no supporting data, thus it is speculation, but this could be the driver of reduced in-socket pressures reported when using a hydraulic ankle-foot device [13]. In addition, the improved forward COP progression and shank angular velocity (that was displayed in all participants except P1) when using the hydraulic ankle-foot device, reflected smoother centre of mass progression during prosthetic stance. The increase in minimum forward COP velocity in all participants (including P2, though remaining marginally negative) also reflected a reduction in the ‘dead spot’ reported by some individuals with lower limb amputation, as progression over the prosthetic limb is interrupted during stance phase. When considered together, these factors point to an overall reduced 'braking effect' [12], particularly during early stance, when using the hydraulic ankle-foot device. It would seem that shifting the functional requirements from the biological structures to the mechanical device during early stance is potentially beneficial, where individuals exchange the static stability of the non-articulating rigid ankle-foot device for the dynamic ability of the hydraulically articulating ankle-foot device. Future research should attempt to investigate whether similar effects are observed in the same patient group when performing other, commonly encountered activities of daily living such as stepping, stair ascent/descent and walking on slopes and uneven surfaces.

There were only five participants in the current study, however research has shown that reactions to a change of prosthetic device are specific to the individual [4]. Often within a cohort study, a significant group effect is observed between conditions, while some individuals within the group display no, or the opposite reaction. The increased walking speed, when using the HYD, was present for all participants. Likewise, the biomechanical differences that occurred between device conditions were consistent, and almost ubiquitous, across participants. Only one individual did not present increased angular velocity of the prosthetic shank when using the HYD. All others responded as hypothesised across all outcome variables. Therefore, despite the small sample size, we feel that the findings from the current study are of clinical relevance at both the individual level and also to national health care providers. The demonstrated increases in walking speed suggest that improved mobility in an individual may be achieved via prescription. This increased mobility could possibly lead to subsequent improved completion of daily tasks and/or engagement in social activities. In addition, given that patients themselves previously reported a perceived benefit of such devices to mobility and prosthetic satisfaction [15], this could suggest that widespread use of such devices may be beneficial to the wider body of less active individuals living with unilateral transtibial amputation. However, prior to the widespread adoption of such devices, the long-term effects and potential benefits to both the individual and healthcare systems of such hydraulically articulating ankle-foot devices must be established and should be the focus of future investigation.

Limitations

There are a number of limitations to the current study, the most obvious of which is the size of the sample, which was limited to include only individuals who used the specified components in order to prevent any differences being due to the foot, itself, rather than the change in attachment. Although the sample size was only five individuals, prosthetic prescription is made on an individual basis. For every participant in the current study, large and consistent effects were observed, thus authors feel that the presented results are still valid. Authors do, however, acknowledge that confirmatory future research should attempt to assess whether these magnitudes of effect are maintained in the wider patient population. Also, the effects observed in the current study were acute (same day) and do not speak to any long-term effects. This begs the question as to whether these difference would be maintained over longer periods of time and what the subsequent influences would be on physical activity and quality of life. This not answerable by the current study but warrants further investigation. Finally, a highly experienced prosthetist with knowledge of all of the components, made all adjustments in the current study. However, where this is not possible, it remains to be seen if similar effects would be observed.

Conclusion

Individuals with unilateral transtibial amputation who are described as K2 by their prescribing physician walk faster when using a non ESR-foot with a hydraulically articulating attachment when compared to an identical foot with a rigid, non-articulating attachment. This improvement in walking performance can be partially explained by a reduced ‘braking effect’ in early stance as a result of the action of the hydraulic component present in the articulating attachment.

Acknowledgements

Authors would like to thank Chas. A. Blatchford and Sons for providing prosthetic components and prosthetist assistance in the current study. Chas. A. Blatchford and Sons had no role in the study design; data collection, analysis and interpretation; manuscript writing or decision to submit for publication.

Declaration of Interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References

[1] AR De Asha, L Johnson, R Munjal, J Kulkarni, JG Buckley. Attenuation of centre-of-pressure trajectory fluctuations under the prosthetic foot when using an articulating hydraulic ankle attachment compared to fixed attachment, Clin.Biomech. 28 (2013) 218-224.

[2] AR De Asha, R Munjal, J Kulkarni, JG Buckley. Walking speed related joint kinetic alterations in trans-tibial amputees: impact of hydraulic'ankle’damping, Journal of neuroengineering and rehabilitation. 10 (2013) 107.

[3] Johnson, L, De Asha, AR, Munjal, R, Kulkarni, J and Buckley, JG. Toe clearance when walking in people with unilateral trans-tibial amputation: Effects of passive hydraulic ankle, Journal of Rehabilitation Research and Development. 51 (2014) 429-438.

[4] AR De Asha, CT Barnett, V Struchkov, JG Buckley. Which Prosthetic Foot to Prescribe?: Biomechanical Differences Found during a Single-Session Comparison of Different Foot Types Hold True 1 Year Later, JPO: Journal of Prosthetics and Orthotics. 29 (2017) 39-43.

[5] RL Waters, J Perry, D Antonelli, H Hislop. Energy cost of walking of amputees: the influence of level of amputation, J.Bone Joint Surg.Am. 58 (1976) 42-46.

[6] C Barnett, N Vanicek, R Polman, A Hancock, B Brown, L Smith, et al. Kinematic gait adaptations in unilateral transtibial amputees during rehabilitation, Prosthet.Orthot.Int. 33 (2009) 135-147.

[7] CT Barnett, RC Polman, N Vanicek. Longitudinal kinematic and kinetic adaptations to obstacle crossing in recent lower limb amputees, Prosthet.Orthot.Int. (2013).

[8] C Barnett, R Polman, N Vanicek. Longitudinal changes in transtibial amputee gait characteristics when negotiating a change in surface height during continuous gait, Clin.Biomech. 29 (2014) 787-793.

[9] L Nolan, A Wit, K Dudziński, A Lees, M Lake, M Wychowański. Adjustments in gait symmetry with walking speed in trans-femoral and trans-tibial amputees, Gait Posture. 17 (2003) 142-151.

[10] HS Ranu. An evaluation of the centre of pressure for successive steps with miniature triaxial load cells, J.Med.Eng.Technol. 12 (1988) 164-166.

[11] M Schmid, G Beltrami, D Zambarbieri, G Verni. Centre of pressure displacements in trans-femoral amputees during gait, Gait Posture. 21 (2005) 255-262.

[12] AK Silverman, RR Neptune. Muscle and prosthesis contributions to amputee walking mechanics: a modeling study, J.Biomech. 45 (2012) 2271-2278.

[13] S Portnoy, A Kristal, A Gefen, I Siev-Ner. Outdoor dynamic subject-specific evaluation of internal stresses in the residual limb: hydraulic energy-stored prosthetic foot compared to conventional energy-stored prosthetic feet, Gait Posture. 35 (2012) 121-125.

[14] AR De Asha, R Munjal, J Kulkarni, JG Buckley. Impact on the biomechanics of overground gait of using an 'Echelon'hydraulic ankle–foot device in unilateral trans-tibial and trans-femoral amputees, Clin.Biomech. 29 (2014) 728-734.

[15] R Moore. Patient Evaluation of a Novel Prosthetic Foot with Hydraulic Ankle Aimed at Persons with Amputation with Lower Activity Levels, JPO: Journal of Prosthetics and Orthotics. 29 (2017) 44-47.

[16] C Barnett, M Bisele, J Jackman, T Rayne, N Moore, J Spalding, et al. Manipulating walking path configuration influences gait variability and six-minute walk test outcomes in older and younger adults, Gait Posture. 44 (2016) 221-226.

[17] D Brooks, J Parsons, JP Hunter, M Devlin, J Walker. The 2-minute walk test as a measure of functional improvement in persons with lower limb amputation, Arch.Phys.Med.Rehabil. 82 (2001) 1478-1483.

[18] LE Powell, AM Myers. The Activities-specific Balance Confidence (ABC) Scale, J.Gerontol.A Biol.Sci.Med.Sci. 50A (1995) M28-34.

[19] M Devlin, T Pauley, K Head, S Garfinkel. Houghton scale of prosthetic use in people with lower-extremity amputations: reliability, validity, and responsiveness to change, Arch.Phys.Med.Rehabil. 85 (2004) 1339-1344.

[20] BJ Hafner, IA Gaunaurd, SJ Morgan, D Amtmann, R Salem, RS Gailey. Construct Validity of the Prosthetic Limb Users Survey of Mobility (PLUS-M) in Adults With Lower Limb Amputation, Arch.Phys.Med.Rehabil. (2016).

[21] KZ Takahashi, TM Kepple, SJ Stanhope. A unified deformable (UD) segment model for quantifying total power of anatomical and prosthetic below-knee structures during stance in gait, J.Biomech. 45 (2012) 2662-2667.

[22] J Cohen. Statistical power analysis for the behavioral sciences . Hillsdale, NJ: Lawrence Earlbaum Associates, Inc, Publishers. (1988).

[23] P Page. Beyond statistical significance: clinical interpretation of rehabilitation research literature, Int.J.Sports Phys.Ther. 9 (2014) 726-736.

[24] MJ Brown, LA Hutchinson, MJ Rainbow, KJ Deluzio, AR De Asha. Comparison of self-selected walking speeds and walking speed variability when data are collected during repeated discrete trials and during continuous walking, Journal of applied biomechanics. (2017) 1-14.

[25] WC Miller, M Speechley, B Deathe. The prevalence and risk factors of falling and fear of falling among lower extremity amputees, Arch.Phys.Med.Rehabil. 82 (2001) 1031-1037.

[26] R McNeill Alexander. Energetics and optimization of human walking and running: the 2000 Raymond Pearl memorial lecture, Am.J.Hum.Biol. 14 (2002) 641-648.