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Title: **DEVELOPMENT OF A LIMITS OF STABILITY PROTOCOL FOR USE IN TRANSTIBIAL PROSTHESIS USERS: LEARNING EFFECTS AND RELIABILITY OF OUTCOME VARIABLES**

Format: Original Article

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All authors were fully involved in the study and preparation of the manuscript and that the material within has not been and will not be submitted for publication elsewhere.

Highlights

- Limits of Stability can be assessed using typical biomechanics laboratory equipment
- Most Limits of Stability variables are reliable for transtibial prosthesis users
- Reaction time variable has poor reliability
- Learning effect in directional control removed by conducting one practice trial

Abstract

The aims of this study were to empirically quantify reliability and learning effects of a Limits of Stability protocol for transtibial prosthesis users. Outcome variables from center of pressure and center of mass were tested on: 1) multiple test repetitions within a single test occasion; and 2) between multiple test occasions. Trantibial prosthesis users (n=7) and matched controls (n=7) executed five trials of the Limits of Stability protocol on two occasions per day, on two consecutive days. Inter-trial learning effects and reliability of outcomes extracted via center of mass and center of pressure were evaluated utilizing standard biomechanics laboratory equipment. Reliability was good to excellent except the reaction time variable which was poor (Pooled 95%CI of ICC=0.248-0.484). An inter-trial learning effect was present in directional control for prosthesis users when the first trial was included in analysis (center of mass: 95%CI of r=0.065-0.239; center of pressure: 95%CI of r=0.076-0.249). The use of standard biomechanics lab equipment can produce reliable results for the Limits of Stability protocol. Researchers should be aware of low reliability of reaction time variable in the protocol assessed and should execute at least one practice trial prior to that which is used in subsequent analysis.

Keywords: **Balance, Postural Control, Amputee, Prosthesis, Limits of Stability**

1 Introduction

In order to stand and ambulate, an individual must be able to coordinate complex movements in an appropriate fashion without falling, thus allowing them to execute activities of daily living (ADLs) [1-3]. Individuals who have undergone a transtibial amputation and utilize a prosthesis for ambulation, have increased fear of falling [4, 5], increased incidence of falling [6, 7], decreased access to meaningful physical activity [8], with research suggesting compromised postural stability and postural control in this group [9]. Therefore, research into postural control of prosthesis users is necessary to direct future treatment of these individuals with the hope of reducing fall injuries, increasing access to physical activity, increased ability to execute ADLs. Much of what is known about postural stability in transtibial prosthesis users (TPUs) comes from static measures [9-12] that show prosthesis users have increased movement of the center of pressure (CoP) in the mediolateral (ML) and anteroposterior (AP) directions [11, 13] and that measures associated with instability in the AP direction are also present when the postural task is more challenging [12, 13]. Additional research into dynamic tasks has also

included the Limits of Stability (LoS) protocol, which assesses volitional control of body movements and has been utilized in able-bodied individuals [14, 15], elderly [14, 16], elderly fallers [17], stroke patients [18] and prosthesis users [19-23]. Results have shown that prosthesis users have compromised accuracy directed posteriorly, and both accuracy and stability limits towards the prosthetic side [22], although variables associated with accuracy improve in the 6 month period following amputation [20]. It has also been shown that angular alignment adjustments of the foot up to 5 degrees (plantarflexion/dorsiflexion) do not have an effect on outcome of the LoS protocol [19].

There are multiple systems that can evaluate LoS [24, 25]. These different systems typically rely on extracting outcomes from forceplate data which is proprietary to manufacturers. Recently a validation of the LoS protocol was conducted using motion analysis and center of mass (CoM) of able-bodied and transtibial prosthesis users [23]. Results indicated varying levels of correlation between resultant CoP data from a single forceplate and CoM data for outcomes in the LoS protocol. As these studies rely on procurement of manufacturer specific proprietary equipment, it is also imperative to develop a non-proprietary method of evaluating LoS using equipment such as multiple forceplates and motion analysis systems that are often times already available in many biomechanics laboratories.

Currently, reliability of the LoS protocol has been documented in multiple patient groups including young able-bodied individuals (Intraclass Correlation Coefficient (ICC)=maximum excursion range (0.88-0.93))[15], able-bodied young and elderly (ICC=path length (0.78), movement time (0.83)[14], stroke patients (ICC=movement path (0.88), movement time (0.84)[18], elderly fallers (Generalizability coefficient=0.58–0.87) [17] [16-18]. Although these values suggest moderate to high reliability of at least path length and movement time, empirical reliability of all outcome variables in the LoS protocol in TPUs is unknown. This is significant as measures of postural control, such as the LoS, must be both valid and reliable in order to draw sound conclusions from results. So as to empirically evaluate reliability of the LoS from both CoM and CoP it is necessary to develop a non-proprietary method for use clinically with prosthetic users.

Therefore, the aims of this study were to empirically quantify, for transtibial prosthesis users, both reliability and learning effects present in Limits of Stability outcome variables from center of pressure and center of mass on: 1) multiple test repetitions within a single test occasion; and 2) between multiple test occasions. Experimental hypotheses are that: 1) there will be adequate reliability of methods of LoS calculation based on CoP and CoM, 2) there will

be variation between outcome variables in their reliability, and 3) there will be learning effects present.

2 Methods

2.1 Participants

An experimental group of unilateral transtibial prosthesis users (TPU; n=7, (mean(SD): age=54.1(10.7)years, weight=81.4(16.2)kg, height=177.6(6.7)cm) was recruited on the basis that they; had a unilateral transtibial amputation with no concomitant health issues, no current issues regarding fit or function of the prosthesis including wounds, blisters, or skin breakdown and had been a regular prosthesis user for at least one year. A matched control group (CON; n=7) was also recruited (mean(SD): age=49.3(12.7)years, weight=83.0(7.5)kg, height=180.0(6.9)cm). All participants gave written, informed consent to participation which was approved by the Regional Ethical Review Board in Linköping, Sweden.

2.2 Experimental Protocol

Prior to testing participants were fitted with a safety harness. Participants stood with each of their feet located on one of two forceplates (BP400600, AMTI, Inc.; Watertown, USA). Foot position on the forceplates was determined and maintained based on dimensions used within the Limits of Stability (LoS) protocol [26]. Participants then completed the LoS test protocol while facing a projector screen showing them real-time position of their resultant center of pressure. The LoS protocol is a test of participant's ability to voluntarily shift their body, following a visual and auditory cue, from a central position out towards one of eight goals located anteriorly, anterior/right, right, posterior/right, posterior, posterior/left, left, anterior/left.

Participants received no practice session, simply an explanation of the test protocol. Individual trials towards 8 goal positions from each test session were completed in a randomized order. Following test session completion, there was a rest period of 1-2 minutes before beginning subsequent test sessions. In total, participants completed the LoS protocol 20 times over four test sessions in two days. Each occasion consisted of five repetitions of the LoS protocol. Duration for each occasion was 20-25 minutes. There were two test sessions on both day one and a second day separated by 24-48 hours. Within day test occasions were separated between 3-6 hours.

Passive-reflective markers (69) were placed on anatomical landmarks and joints in order to define the body as a 13-segment system (head, upper and lower arms, hands, torso, pelvis, thigh,

shank and foot segments bilaterally). Full-body kinematics were collected using an 11-camera Oqus motion analysis system (Qualisys AB; Gothenburg, Sweden) with marker coordinate and force data sampled at 100Hz using Qualisys Track Manager (Qualisys AB; Gothenburg, Sweden). All data were then exported to Visual 3D (C-Motion, Inc.; Germantown, USA) for post-processing.

2.3 Data Analysis

Prior to data collection, a standing calibration file was collected to determine position of center of mass (CoM) for each participant. Mean height of CoM was then utilized to create LoS goal positions for each participant. Using theoretical LoS angular goals which have been published elsewhere (7° anterior, 5° posterior, 8° left/right, 6° left/right posterior, 7.45° left/right anterior) [15] goal positions were determined individually for each participant representing 110% of theoretical maximum angle of inclination goal angles. These goal positions were then projected on the screen in front of participants in combination with real-time projection of the CoP.

Following data collection, identical analysis was conducted on CoM and CoP coordinates to extract outcome variables. The coordinate system for analysis was converted from the global lab-based system to a local goal-based coordinate system where x-y-z referred to: movements not towards goal (x) (positive x-direction defined as 90 degrees to the right (clockwise) from the positive y-direction; negative x-direction defined as 180 degrees from the positive x-direction, movements towards goal (y) (positive y-direction defined as that towards the goals; negative defined as 180 degrees from positive y-direction, and movements in vertical direction (z–perpendicular to plane formed by x and y) (positive z-direction defined as superior/up and negative z-direction defined as inferior/down). This transformation aided analysis as movements both towards - and deviations from - the goal were defined in the same coordinate system, regardless of which goal was under consideration. This meant, for instance, a movement towards the goal would always be in the positive y-direction, irrespective of goal direction. Raw marker coordinate and CoP data were low-pass filtered using a second-order Butterworth filter with a cut-off frequency of 3 Hz. This processed data was used in all subsequent analyses.

Angle of inclination based on CoP

A single resultant CoP for both feet was extracted from two forceplates and utilized in analysis. Angle of inclination derived from CoP (Θ_{CoP}) was calculated by identifying 3 points: 1) x/y position of CoP at cue to start, 2) a vertical projection of point 1 at mean height of CoM as calculated in calibration file in lab-coordinate system, and 3) this vertical projection (point

2) throughout 8 second trial. Where points 1, 2 and 3 form a triangle, the angle was then defined as that formed between line $\overline{12}$ and line $\overline{13}$ (Figure 2A).

Angle of inclination based on CoM

Angle of inclination derived from CoM (Θ_{CoM}) was calculated by identifying 3 points: 1) x/y/z position of CoM at cue to start at, 2) a vertical projection of point 1 at support-surface (z=0), and 3) movement of point 1 throughout 8 second trial. Where points 1, 2 and 3 form a triangle, the angle was then defined as that formed between line $\overline{12}$ and line $\overline{13}$ (Figure 2B).

INSERT FIGURE 1

Each angle of inclination was derived (Θ_{CoP} and Θ_{CoM}) and used to calculate outcome variables (Directional Control (DC_{CoP} and DC_{CoM}), Maximum Excursion (MXE_{CoP} and MXE_{CoM}), End Point Excursion (EPE_{CoP} and EPE_{CoM}), Reaction Time (RT_{CoP} and RT_{CoM}), and Mean Velocity (MVL_{CoP} and MVL_{CoM})).

DC was defined as proportion of movement in intended direction compared to movement not in intended direction. It was defined by integrating the angular time/position curve using trapezoidal rule for each of x- and y-planes for each of the 8 second trials. Then, a proportion (%) was calculated based on the following formula:

$$\left(\left(\int y - \int x\right) \Big/ \int y\right) \times 100$$

where $\int y$ was sum of all motion towards goal, and, where $\int x$ was sum of all motion not towards goal. DC is expressed in percent (%).

EPE was defined by locating the first local maximum of angular excursion time curve during the eight second trial. It was identified as the first peak following cue to start where the angle excursion curve exhibits zero slope. EPE is expressed in degrees (°).

MXE was defined by locating the global maximum of angular excursion time curve during the 8 second trial. This represents the greatest angular excursion participants were able to attain in intended direction. MXE is expressed in degrees (°).MV was defined by calculating first derivative of angular position/time curve. Then a 5% and 95% percent threshold were established for total angular distance from start position to EPE position. The outcome was then calculated based on mean first derivative of angular position/time curve between these 5% and 95% thresholds. MV is expressed in degrees per second (°/s).RT was defined by calculating root-mean-square (RMS) value of angular position/time curve for 2 seconds preceding cue to

move. RT variable was then identified by locating the instant when angular excursion surpassed this RMS value for the first time in intended direction. RT is expressed in seconds (s).

2.4 Statistical Analysis

Inter-trial learning effect was analyzed using Pearson product-moment correlation coefficients (*r*) for each of the outcome variables (DC, EPE, MXE, MV, RT) where outcome variables are dependent variable and test occasion (1,2,3,4) the independent variable. Inter-trial learning effect was defined as a statistically significant correlation coefficient (*r*)(positive or negative) [27-29]. 95% confidence intervals of *r* for each test occasion were calculated.

Inter-test reliability was assessed for each outcome variable (DC, EPE, MXE, MV, RT) using Intraclass Correlation Coefficients (ICC) utilizing a two-way random model (ICC(2, 7)) as this controls for any rater effect in the estimate of reliability and assumes that the estimate is drawn from a sample, not a population. The average measure for within-visit test-retest reliability (visit 1-4) for test repetitions 2-5. An absolute agreement metric was utilized in analysis. 95% confidence intervals of ICC were calculated for each test occasion. Statistical significance was determined using a critical alpha level of α=0.05 for all tests. Utilizing the ICC, further analysis was conducted so as to produce the Standard Error of Measurement [30].

A three-way repeated measures ANOVA was conducted to determine effects of Group (TPU-CON), Occasion (1-4), and Repetition (2-5) on each outcome variable (DC, EPE, MXE, MV, RT). Greenhouse-Geisser adjusted values were interpreted when violations to sphericity were present. Bonferroni adjustments were applied to post-hoc comparisons.

3 Results

Data were inspected to identify various trials where results were deemed unfit for analysis. This was often due to algorithm errors during data processing stage. Examples of this included percentages greater than 100 or less than 0 or reaction times less than 0 (or greater than 8 seconds). This resulted in a total of approximately 7% of data being removed from analysis (166 of 2240 trials). Descriptive data for outcomes variables (DC, EPE, MXE, MV, RT), including 95%CIs are provided in Table 1.

INSERT TABLE 1

Learning Effects

All outcome variables for both groups had non-significant correlations except for directional control (DC) in TPU group (DC CoM: 95%CI of r=0.065–0.239; DC CoP: 95%CI of r=0.076–0.249)(Table 2A; Figure 2A). This statistically significant positive correlation was not present when only repetitions 2-5 were analyzed (DC CoM: 95%CI of r=-0.051–0.134; DC CoP: 95%CI of r=-0.011–0.195)(Table 2B; Figure 2A). The 95%CI contained a zero value in the second analysis, indicating statistical absence of a learning effect when only trials 2-5 were included.

INSERT FIGURE 2
INSERT TABLE 2

Reliability

ICC were assessed and ranked accordingly to poor=< 0.4, fair=0.4–0.59, good=0.6–0.74, excellent=0.75–1.0. [31]. In addition, an ICC<0.7 signified the test appropriateness for group analysis e.g. research contexts, whereas an ICC<0.9 signified the test for individual participants e.g. clinical contexts [32].Directional control (DC) showed fair to excellent reliability for both groups during all occasions and repetitions (Pooled 95%CI of ICC=0.645-0.755)(Table 3). End-point excursion (EPE) showed good to excellent reliability (Pooled 95%CI of ICC=0.818-935) and Maximum excursion (MXE) showed excellent reliability (Pooled 95%CI of ICC=0.965-0.973). Mean velocity (MV) showed good to excellent reliability (Pooled 95%CI of ICC=0.780-0.858). Reaction time (RT) showed poor to good reliability (Pooled 95%CI of ICC=0.248-0.484). Results of the three-way repeated measures ANOVA showed a significant two-way Group*Occasion interaction, $F(3, 54)=3.972$, $p=.025$ for Reaction time (RT) variable. All other three-way and two-way interactions for Group, Occasion, or Repetition were not statistically significant for each remaining outcome variables (DC, EPE, MXE, MV)(Table 3).

INSERT TABLE 3

4 Discussion

The aims of this study were to empirically quantify, for transtibial prosthesis users, both reliability and inter-trial learning effects present in Limits of Stability outcome variables from center of pressure (CoP) and center of mass (CoM) on multiple test repetitions within a single test occasion and between multiple test occasions. There was a learning effect if one considered all five repetitions in one visit, but this effect was reduced if one only considered repetitions 2-

5. Results show that reliability is generally high for the outcome variables except for reaction time, which showed low reliability.

The first hypothesis was partially confirmed, and the second hypothesis was confirmed. Directional control (DC) showed reliability which was of fair to excellent [31]. Of interest is that this ICC was of lower magnitude than movement velocity (MV), end-point excursion (EPE) and maximum excursion (MXE), something that was also seen in all studies looking at reliability of DC that the authors are aware of with ICC values ranging from 0.58 to 0.84 [14, 16-18, 24, 25]. This suggests that DC is as reliable in TPUs as it is in other participant groups that have been assessed, including able-bodied and various patient groups. Both EPE and MXE showed greatest reliability in both CoP and CoM outcome variables (good to excellent and excellent, respectively). This is also in agreement with literature which shows ICC values ranging from 0.80 to 0.91 [15-17, 24, 25]. MVL showed good to excellent reliability (Pooled 95%CI of ICC=0.780-0.858) which was similar to values from the literature approximately 0.8 (ICC) [24, 25] and related but not identical variable movement time (range ICC=0.88 to 0.83) [14, 18]. Of concern is reliability of the reaction time variable. This variable showed poor to good reliability (Pooled 95%CI of ICC=0.248-0.484). There was only one other literature source which evaluated reliability of reaction time which reported good reliability (ICC<0.8) for reaction time composite score [25]. However, the current study did not investigate reliability of composite scores. Mean composite scores, which do not account for direction (as in current study), would appear to have an attenuating effect on ICCs. When Alsalaheen, Haines [25] took account of direction (secondary analysis) they found RT had more much variation (ICC range=0.00 to 0.64). This concurs with data from the current study and would suggest that reliability of RT (in able-bodied and TPUs) should be interpreted based on whether direction was accounted for or omitted by analyzing summary coefficient values. All outcome variables, except for RT, had ICCs of sufficient magnitude to warrant their use in a research context, ie. group comparisons [32]. Additionally, both EPE and MXE had magnitudes warranting use in clinical contexts, ie. individual comparisons. It is recommended to researchers and clinicians to be conscious of varying levels of reliability within outcome variables of the LoS protocol when investigating transtibial prosthesis users, particularly in evaluation of reaction time.

Hypothesis number three was also confirmed as there was presence of an inter-trial learning effect in directional control when correlation coefficients included trials 1-5. With removal of the first trial from analysis this statistically positive correlation between repetition and directional control was not present. This is the first study to directly investigate learning effects of any kind in the LoS protocol in any patient group. Results suggest that for TPUs,

investigators should complete at least one full repetition of the test protocol before collecting data used in analysis of postural control. Of interest is that participants received no practice session, which is common in the literature [16, 17, 24, 25], suggesting that any learning effect can be reduced by execution of a full practice trial instead. Results also suggest that further practice after the first trial did not have an additional effect on outcome variables.

There are limitations present in the current study. Although groups are matched and similar in characteristics, it is possible results may only reflect similar individuals, particularly in relation to TPUs which who whilst not highly active, were reasonably mobile. In addition, the current sample size may also limit the precision of the reliability estimates. Therefore, caution should be exercised when generalizing conclusions to TPUs with other characteristics, such as those having an amputation for reasons other than trauma, relatively young participants, females, and those who have had a recent amputation, given the size and characteristics of the sample from the current study.

In summary, results of this study clearly show that the LoS protocol is sufficiently reliable on a clinical level to draw sound conclusions based on directional control, movement velocity and two measures of excursion for TPUs. Though, researchers should be cautious in conclusions drawn from the reaction time variable, as reliability was much lower than other variables. Results were also similar between CoP and CoM outcome variables and suggest non-proprietary equipment often found in a biomechanics laboratory are also capable of contributing to highly reliable research in this area. Although not within the scope of the current study, future research should also address the reliability and learning effects of postural control associated with each limb in prosthesis users in study designs such as that employed in the current study. These analyses may reveal asymmetries specific to unilateral limb loss not detected using the LoS test in its standard form.

5 Conclusions

Limits of Stability outcome variables based on center of mass and center of pressure, as evaluated using the methods in this investigation, are of fair to excellent reliability and sound conclusions can be drawn based on results. The exception to this was reaction time, which is of low reliability, and researchers' conclusions should be drawn cautiously with this factor in mind. A learning effect which is present in directional control can be reduced by repeating the protocol at least twice, and limiting analysis to the second trial.

Conflict of interest statement

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

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Supplementary Material

The required files for the execution of the LoS protocol as described in this project (including set-up for the Limits of Stability protocol and Visual 3D pipeline for processing) are available upon request from the corresponding author. In the event that this material is utilized, the authors ask only that reference and citation is made to this article.

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Figure 1 – Graphical description of angles of inclination θ_{CoP} (A – left), and θ_{CoM} (B – right). A: CoP_1 = x/y position of CoP at start of trial, $VCoP_1$ = vertical projection of CoP at start of trial, CoP_n = subsequent position of CoP following start of trial (2, 3, … n), $VCoP_n$ = subsequent position of VCoP following start of trial (2, 3, … n), h = mean z-position of CoM during calibration trial. B: CoM_1 = x/y position of CoM at start of trial, $VCoM_1$ = vertical projection of CoM at support-surface at start of trial, CoM_n = subsequent position of CoM following start of trial (2, 3, … n), h_1 = z-position of CoM at start of trial, h_2 = subsequent z-position of CoM following start of trial (2, 3, … n). Coordinate description: y-direction represents movements towards the goal, x-direction represents movements not towards the goal, z-direction movements represent vertical direction.

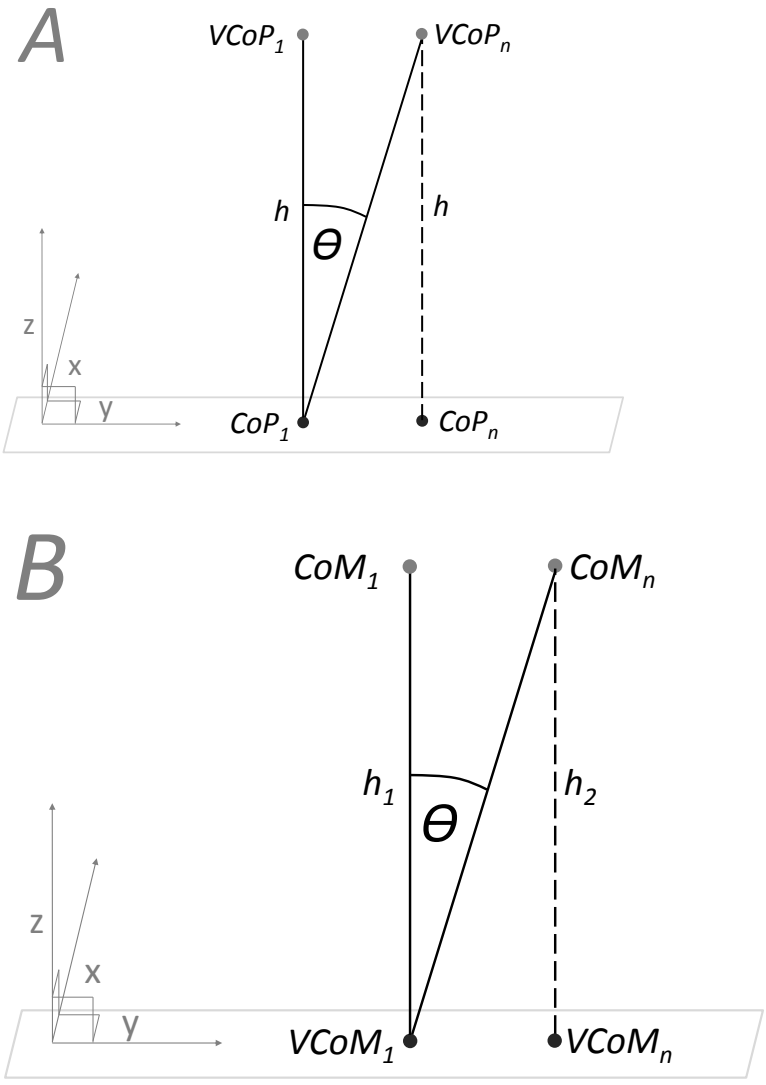

Figure 2 – Learning effect: Scatterplot of Directional Control (DC - %) and Repetition (1,2,3,4,5) for each Test Occasion (1,2,3,4) for the TPU Group (TPU – black dots) and Control Group (CON – grey dots). The data above (A - top) includes the full set of repetitions (1,2,3,4,5) and the data below (B – bottom) includes occasion 2-5 (test repetition 1 omitted). The results graphically show how the statistically significant correlation coefficient (r) in test occasion one (left side, top) is omitted when the analysis only contains repetitions 2-5 (left side, bottom)

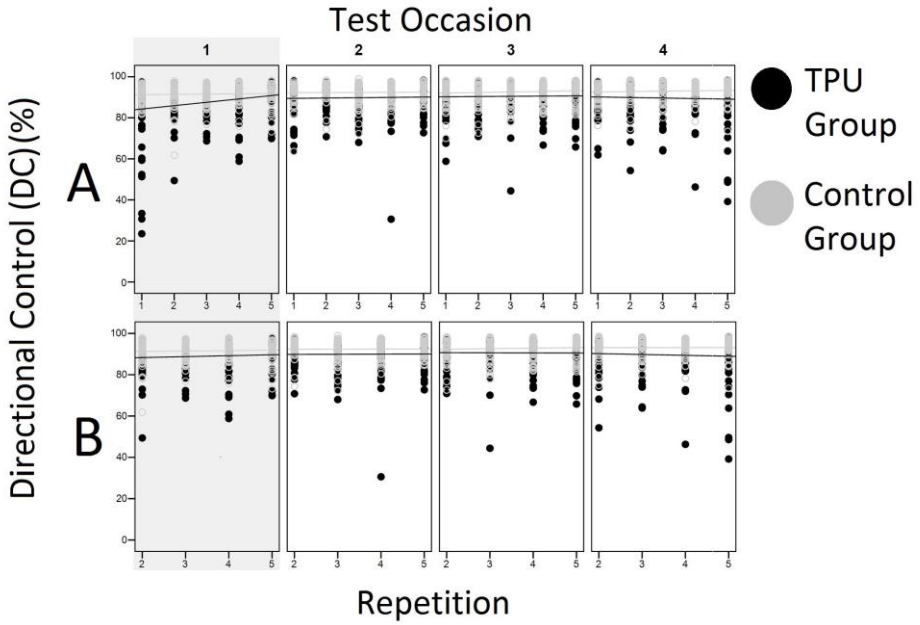

Table 1 - Participant characteristics for TPU-group (white section) and CON-group (shaded section). Sex (M=male, F=Female), Height, Weight, Age, YSA=years since amputation, Cause=amputation cause, Foot=prosthetic foot classification as defined by Hafner [32], Suspension=suspension form of prosthesis.

	Participant	Sex	Height (cm)	Weight (kg)	Age (years)	YSA	Cause	Foot	Suspension	Control	Sex	Height	Weight	Age
	1	M	183	81	66	18	Trauma	ESAR	Vacuum	C1	M	177	81	37
	2	M	187	87	45	27	Trauma	ESAR	Seal-in	C2	M	186	88	39
	3	M	179	70	49	6	Trauma	ESAR	Vacuum	C3	M	183	87	48
	4	M	176	87	52	8	Trauma	ESAR	Vacuum	C4	M	176	73	65
	5	M	179	58	62	21	Trauma	ESAR	Pin	C5	M	191	92	49
	6	M	167	110	39	18	Trauma	ESAR	Vacuum	C6	M	176	87	68
	7	M	172	77	66	10	Trauma	ESAR	Pin	C7	M	171	73	39
	mean(SD)	*M=7; F=0*	*177.6(6.7)*	*81.4(16.2)*	*54.1(10.7)*	*15.4(7.7)*					*M=7; F=0*	*180.0(6.9)*	*83.0(7.5)*	*49.3(12.7)*

		M=17;F =4	177.6	81.4	54.1	15.4						180.0	83.0	49.3
			6.7	16.2	10.7	7.7						6.9	7.5	12.7

Table 2 – Descriptive statistics (mean and 95% confidence interval) for each outcome variable (DC, EPE, MXE, MV, RT) based on the center of mass (CoM) and center of pressure (CoP) for each group (TPU & CON). DC units in percent (%); EPE & MXE units in degrees (°), MV units in degrees/second (°/s), RT units in seconds (s).

		DC				EPE				MXE				MV				RT			
CoM	TPU	89.4	88.8	-	89.9	5.3	5.2	-	5.3	5.7	5.7	-	5.8	2.9	2.8	-	3.0	0.47	0.46	-	0.48
	CON	92.3	92.1	-	92.6	5.8	5.7	-	5.9	6.2	6.2	-	6.3	3.2	3.1	-	3.3	0.49	0.48	-	0.50
CoP	TPU	83.7	83.0	-	84.4	4.8	4.7	-	4.9	6.0	5.9	-	6.1	8.0	7.7	-	8.3	0.70	0.69	-	0.71
	CON	87.4	87.0	-	87.9	5.5	5.4	-	5.7	6.6	6.5	-	6.7	10.1	9.5	-	10.6	0.76	0.74	-	0.77

Table 3 – Learning effect: Mean Pearson product-moment correlation coefficient (r), 95% confidence interval and p-value for each outcome variable (DC, EPE, MXE, MV, RT) during test occasion 1 for TPU group (TPU) and Control group (CON). A: The results when repetitions 1-5 are included in the analysis; B: The results when only repetitions 2-5 included in the analysis (test repetition 1 omitted). Data from Directional Control (DC) (bold text) coincides with the data presented graphically in Figure 3.

	Group		DC_CoM	DC_CoP	EPE_CoM	EPE_CoP	MXE_CoM	MXE_CoP	MV_CoM	MV_CoP	RT_CoM	RT_CoP
	Experimental		0.215	0.231	0.060	0.065	0.075	0.031	0.046	-0.029	0.009	0.114
	n=247		0.001	0.000	0.346	0.307	0.239	0.632	0.473	0.652	0.894	0.073
	Control		0.037	0.087	0.098	0.076	0.043	0.066	0.056	0.023	0.098	0.111
	n=263		0.547	0.159	0.112	0.218	0.490	0.289	0.367	0.713	0.111	0.073
	Experimental		0.063	0.125	0.002	0.013	0.051	0.017	0.069	-0.019	0.018	0.093
	n=196		0.378	0.080	0.975	0.855	0.480	0.813	0.337	0.788	0.803	0.194
	Control		0.046	0.080	0.041	0.016	0.022	0.038	-0.017	0.007	0.076	0.110
	n=212		0.505	0.245	0.549	0.821	0.749	0.582	0.807	0.914	0.273	0.111
			DC		**EPE**		**MXE**		**MV**		**RT**	
			CoM	CoP	CoM	CoP	CoM	CoP	CoM	CoP	CoM	CoP
A	TPU	*r*	***0.215***	***0.231***	0.060	0.065	0.075	0.031	0.046	-0.029	0.009	0.114
		95&CI of r	***0.065 — 0.239***	***0.076 — 0.249***	-0.046 — 0.131	-0.043 — 0.135	-0.035 — 0.142	-0.067 — 0.110	-0.056 — 0.121	-0.109 — 0.068	-0.083 — 0.095	-0.008 — 0.169
	n=247	*p-value*	***0.001***	***0.000***	0.346	0.307	0.239	0.632	0.473	0.652	0.894	0.073

	CON	*r*	0.037	0.087	0.098	0.076	0.043	0.066	0.056	0.023	0.098	0.111
		95&CI of r	-0.060 — 0.113	-0.024 — 0.147	-0.016 — 0.155	-0.032 — 0.140	-0.056 — 0.116	-0.040 — 0.132	-0.047 — 0.126	-0.070 — 0.102	-0.016 — 0.155	-0.007 — 0.164
	n=263	*p-value*	0.547	0.159	0.112	0.218	0.490	0.289	0.367	0.713	0.111	0.073
B	TPU	*r*	***0.063***	***0.125***	0.002	0.013	0.051	0.017	0.069	-0.019	0.018	0.093
		95&CI of r	***-0.051 — 0.134***	***-0.011 — 0.195***	-0.122 — 0.126	-0.113 — 0.136	-0.077 — 0.163	-0.109 — 0.139	-0.065 — 0.189	-0.136 — 0.104	-0.096 — 0.124	-0.035 — 0.170
	n=196	*p-value*	***0.378***	***0.080***	0.975	0.855	0.480	0.813	0.337	0.788	0.803	0.194
	CON	*r*	0.046	0.080	0.041	0.016	0.022	0.038	-0.017	0.007	0.076	0.110
		95&CI of r	-0.083 — 0.168	-0.049 — 0.192	-0.082 — 0.154	-0.104 — 0.131	-0.103 — 0.143	-0.089 — 0.158	-0.137 — 0.107	-0.113 — 0.127	-0.055 — 0.194	-0.023 — 0.217
	n=212	*p-value*	0.505	0.245	0.549	0.821	0.749	0.582	0.807	0.914	0.273	0.111

Table 4 – Reliability: Mean Intraclass Correlation Coefficients (ICC), 95% confidence interval of ICC, p-value, and Standard Error of Measurement (SEM) [30] from the CoM and CoP for each outcome variable (DC, EPE, MXE, MV, RT) and test occasion (1-4) for TPU group (TPU) and Control group (CON). Units in SEM for outcome variables: DC (percent (%)), EPE (degrees (°)), MXE degrees (°)), MV (degrees per second (°/s), RT (seconds (s).

		TPU								**CON**							
		CoM				CoP				CoM				CoP			
Variable	**Test Occasion**	*ICC*	*95%CI of ICC*	*p-value*	*SEM*	*ICC*	*95%CI of ICC*	*p-value*	*SEM*	*ICC*	*95%CI of ICC*	*p-value*	*SEM*	*ICC*	*95%CI of ICC*	*p-value*	*SEM*
DC	1	0.729	0.553—0.848	0.000	3.81	0.729	0.555—0.847	0.000	5.39	0.740	0.593—0.844	0.000	2.62	0.759	0.62—0.855	0.000	4.10
	2	0.784	0.643—0.879	0.000	2.86	0.847	0.747—0.914	0.000	3.70	0.598	0.372—0.757	0.000	2.88	0.616	0.398—0.769	0.000	5.46
	3	0.758	0.586—0.869	0.000	3.62	0.633	0.374—0.802	0.000	6.57	0.798	0.692—0.874	0.000	2.14	0.779	0.664—0.862	0.000	3.13
	4	0.466	0.124—0.696	0.006	4.45	0.765	0.615—0.866	0.000	6.37	0.646	0.42—0.799	0.000	2.69	0.552	0.266—0.745	0.001	5.26
EPE	1	0.946	0.911—0.970	0.000	0.36	0.837	0.73—0.909	0.000	0.74	0.932	0.893—0.959	0.000	0.38	0.744	0.598—0.847	0.000	0.95

	2	0.959	0.933—0.977	0.000	0.32	0.901	0.836—0.944	0.000	0.59	0.968	0.95—0.981	0.000	0.24	0.596	0.37—0.755	0.000	1.20
	3	0.946	0.908—0.971	0.000	0.34	0.748	0.573—0.863	0.000	0.95	0.972	0.958—0.983	0.000	0.23	0.773	0.654—0.858	0.000	0.81
	4	0.953	0.924—0.973	0.000	0.35	0.912	0.856—0.95	0.000	0.57	0.972	0.954—0.984	0.000	0.24	0.863	0.776—0.922	0.000	0.69
MXE	1	0.956	0.927—0.975	0.000	0.29	0.960	0.934—0.978	0.000	0.30	0.979	0.967—0.987	0.000	0.19	0.965	0.945—0.979	0.000	0.27
	2	0.971	0.952—0.984	0.000	0.24	0.965	0.943—0.981	0.000	0.28	0.979	0.967—0.987	0.000	0.17	0.966	0.947—0.98	0.000	0.25
	3	0.969	0.947—0.983	0.000	0.24	0.973	0.953—0.985	0.000	0.24	0.979	0.967—0.987	0.000	0.17	0.974	0.959—0.984	0.000	0.22
	4	0.957	0.93—0.975	0.000	0.30	0.969	0.949—0.982	0.000	0.29	0.975	0.959—0.986	0.000	0.22	0.974	0.957—0.985	0.000	0.25
MV	1	0.835	0.728—0.907	0.000	0.64	0.806	0.678—0.891	0.000	1.74	0.789	0.669—0.874	0.000	0.71	0.916	0.868—0.95	0.000	2.80
	2	0.800	0.67—0.887	0.000	0.64	0.794	0.661—0.884	0.000	2.21	0.675	0.49—0.805	0.000	0.83	0.945	0.913—0.967	0.000	2.31
	3	0.824	0.7—0.905	0.000	0.65	0.880	0.797—0.935	0.000	1.80	0.733	0.594—0.833	0.000	0.75	0.837	0.751—0.898	0.000	3.31

	4	0.846	0.749—0.912	0.000	0.55	0.886	0.815—0.935	0.000	1.87	0.695	0.499—0.826	0.000	0.72	0.840	0.739—0.908	0.000	2.62
RT	1	-0.132	-0.862—0.362	0.658	0.78	0.333	-0.113—0.628	0.061	0.15	0.595	0.362—0.757	0.000	0.13	0.700	0.53—0.82	0.000	0.13
	2	0.629	0.383—0.792	0.000	0.09	0.310	-0.145—0.613	0.076	0.14	0.483	0.189—0.688	0.002	0.15	0.274	-0.126—0.559	0.077	0.21
	3	0.232	-0.319—0.587	0.168	0.12	0.268	-0.256—0.606	0.128	0.16	0.328	-0.032—0.583	0.035	0.19	0.322	-0.024—0.575	0.033	0.20
	4	0.606	0.357—0.775	0.000	0.11	0.304	-0.143—0.604	0.076	0.14	0.051	-0.56—0.46	0.406	0.39	0.549	0.266—0.742	0.001	0.15