Transition from sitting to standing after trans-femoral amputation

Short title: Standing up after trans-femoral amputation

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Abstract

Standing up is an important and common daily activity. It is essential for independence and a prerequisite for walking. Many elderly and many subjects with impairments have problems with transition from sitting to standing.

The aim of the present study was to find whether there was a difference between the characteristics of standing up in trans femoral amputees and healthy subjects. Five young trans femoral amputees and five healthy subjects were included into the study. They were asked to stand up. The body motion was recorded by Optotrak contactless optical system. The force and moment vectors exerted on the seat were recorded by JR3 six-axis robot wrist sensor. The force under the feet was recorded by two AMTI force plates. The trans femoral amputees were found to stand up more slowly than the healthy subjects. The angles of the hip, knee and ankle joints on the amputated side were different from the angles on the healthy side or in the healthy subjects. There was also a great difference in loading between the healthy and the prosthetic foot. It can be concluded that there are differences in standing up between the trans femoral amputees and the healthy subjects. These differences may be indicating a reason for problems which many elderly trans femoral amputees face when standing up.

Introduction

Standing up is an important and common daily activity often done automatically by healthy subjects (Doorenbosch *et al.* 1994). It is essential for independence and a prerequisite to movements in an upright posture. In spite of the fact that standing up is an action which involves the whole body, the motions of the hip, knee and ankle joints are most important. Biomechanically, standing up can be more demanding than other activities of daily living because it requires more leg strength and greater ranges of joint motion than walking or stair climbing (Hughes and Schenkman 1996). In the United States, it is a problem to more than two million persons older than 64 years (Lundin *et al.* 1995). Inability to stand up does not limit only patients but presents also a greater burden to those who must care for them.

The studies about standing up can be divided into three main categories. The first category tries to determine body kinematics (Fleckestein *et al.* 1988, Kotake *et al.* 1993, Yu *et al.* 2000) and kinetics (Ellis *et al.* 1979, Bajd *et al.* 1982, Németh *et al.* 1984, Burdett *et al.* 1985, Rodosky *et al.* 1989, Kralj *et al.* 1990, Pai and Rogers 1991), myoelectric activities (Munton 1 *et al.* 1984, Stevens *et al.* 1989, Doorenbosch *et al.* 1994, Roebroeck *et al.* 1994), symmetry (Lundin *et al.* 1995), normative data (Kralj *et al.* 1990, Roebroeck *et al.* 1994) and it studies biomechanical models (Bajd *et al.* 1982, Nemeth *et al.* 1984, Fleckestein *et al.* 1988, Rodosky *et al.* 1989, Pai and Rogers 1991). The second evaluates the effects of different parameters such as chair height (Burdett *et al.* 1985, Ellis *et al.* 1984, Rodosky *et al.* 1989), the use of armrests (Seedhom and Terayama 1976, Arborelius *et al.* 1992), the amount of knee flexion (Fleckestien *et al.* 1988), the variation in speed of standing up (Pai and Rogers 1991), the influence of age (Ikeda *et al.* 1991, Schultz *et al.* 1992, Hughes *et al.* 1994, Millington *et al.* 1992) and different strategies of standing up (Doorenbosch *et al.* 1994). The third group studies the standing up of subjects with different impairments, such as spinal cord injury (Bajd *et al.* 1982, Kagava *et al.* 1995, Kamnik *et al.* 1999), arthritis (Munton *et al.* 1984), hemiparesis (Yoshida *et al.* 1983, Hesse *et al.* 1994), certain neuromuscular diseases (Butler *et al.* 1991), functionally impairments (Hughes and Schenkman 1996) and low back pain (Coghlin and Fadyen 1994). There has been no basic study found on standing up of amputees. However, standing up has been used as a functional test to assess the functional ability of lower limb amputees (Burger and Marinček 2001).

The main aim of rehabilitation of lower limb amputees is to enable them to walk again and regain the functional level they had had before the amputation. Before subjects start to walk they have to stand up. Trans femoral amputees have lost two main joints of the lower limb – the ankle and the knee. Also, many muscles around the hip joint have been released and may not be fixed to the bone. Prosthetic joints are completely passive and when performing activities, the subjects have to control them with the remaining muscles. It has been noted by clinical observation that lower limb amputees at the beginning of their rehabilitation and some even later frequently have more problems standing up than walking.

The aim of the present study was to find whether there was a difference between the characteristics of standing up in trans femoral amputees and healthy subjects in order to later develop an appropriate training program and improve their ability to stand up.

Subjects

Five males trans femoral amputees and five healthy subjects composed the study group. We decided to choose trans femoral amputees who were young and fit and who should be able to stand up several times without the help of their upper extremities. All of them had had their prosthesis for at least one year and walked with it without any problems.

The trans femoral amputees were 28 to 51 years old. All had an amputation several years before the measurement (8 – 33 years). All of them were good prosthetic walkers and three of them actively played sitting volleyball. Three of them had an amputation due to an injury, one due to cancer and one due to acute thrombosis (Table 1).

The healthy subjects were 24 to 29 years old (Table 1). None of them had any history of severe lower limb trauma or neurological disease. They were all very active: two of them did regular running up to two kilometres, one did cycling and one did roller-skating.

Prior to the testing, all the subjects were informed of the protocol and signed a consent form.

Include Table 1 here

Include Table 2 here

Methods

The body motion was recorded by Optotrak contactless optical system (Optotrack, Northern Digital Inc., Waterloo, Canada). Infrared markers were attached over the approximate centres of the ankle, knee, hip and shoulder joints in sagital plane. The subjects sat on a commercially available bicycle seat, the height of which was adjusted to 90% of the distance from the floor to the centre of the subject's knee joint. Under the seat was a JR3 six-axis robot wrist sensor (JR3, Inc., Woodland, CA, U.S.A.) which measured the force and moment vectors exerted on the seat. The feet were placed on two AMTI force plates (AMTI Inc., Newton, MA, U.S.A.).

The subjects had their arms crossed over the chest and found a comfortable position of the seat and the feet. They were allowed to find the most comfortable position for the feet on the two plates. They were asked to stand up as naturally as possible and at their most comfortable speed.

Each subject had to do ten stand-ups. The intervals between the trials were one to two minutes long giving the subjects time to rest.

The following measurements were performed:

1. The time to the seat-off (the time from the initiation of the rising manoeuvre to the moment when there was no force measured under the seat).
2. The time from the seat-off to standing (from the time there was no force on the seat to the time the subjects were standing straight and still).
3. The whole time to stand up (from initation of rising to straight and still standing).
4. The angles of the hip, knee and ankle joints on both sides, the trunk angle in all three planes (throughout the testing).
5. The force on the seat and both forceplates (throughout the testing).

The signals from the infrared markers and all three force sensors were collected with a 50 Hz sampling rate. The signals were filtered by the 4th order Butterworth filter with 5 Hz cut-off frequency. The statistical comparisons were made using t-tests.

The characteristic events during raising were detected from the time-courses of the measured reaction forces (Kralj *et al.* 1990). The beginning of the standing-up manoeuvre occurred when the derivative of the sum of all anterior-posterior components (F_{AP}) of the reaction forces rose over 2.5% of the peak to peak value:

$$\left|\frac{dF_{AP}}{dt}\right| \geq 2.5\% \left(\frac{dF_{AP}}{dt}\right)_{PP} \tag{1}$$

Since contrarily to (Kralj *et al.* 1990) the seat reaction force was also measured, it was used to determine the seat-off event. The seat-off instant was detected, when the vertical component of the seat force (F_S) decreased under 5% of its maximal value:

$$F_S \leq 5\% F_{S\max} \tag{2}$$

The occurrence of quiet standing was defined as the instant at which the sum of all vertical components of the reaction forces (F_V) settled within1% of the body gravitational force (F_G):

$$\left| F_V - F_G \right| \leq 1\% F_G \tag{3}$$

The joint angles were calculated from the trajectories of the ankle, knee, hip and shoulder markers. A longitudinal axis of the trunk was defined by the help of two points that were located half the distance between both shoulder and hip markers. The trunk angles in the sagittal, transversal and frontal plane were calculated by projecting the trunk axis on the corresponding planes.

Results

The trans femoral amputees took more time to stand up than the healthy subjects due to longer time from the seat-off to standing (Table 3).

Insert Table 3 here

At the time of the seat-off, trans femoral amputees had both hips and the prosthetic knee more extended than the healthy ones. The prosthetic ankle was less dorsiflexed (Table 4). All trans femoral amputees except one had a straighter hip on the amputated side and three out of five had a more extended prosthetic knee. The angle in the ankle joint on the prosthesis was smaller (Table 4, Figure 1). Their standing up was not as symmetrical as in the healthy subjects (Figure 1).

Insert Figure 1 here

Insert Table 4 here

The trans femoral amputees did not put any load on the prosthesis until they were almost standing up (Figure 2). In all healthy subjects except one, the maximal difference in force between both feet was smaller than 10 % of the maximal force under the feet while in all trans femoral amputees it reached over 70 % of the maximal force under the healthy foot (Table 5). There was significant difference between the knee and the hip angles at the time they put 5% or 95% of the maximal load on the prosthetic foot or on the healthy foot (Table 6).

Insert Figure 2 here

Insert Table 5 here

Insert Table 6 here

The trans femoral amputees leaned more forwards at the time of the seat-off (Table 4), later they leaned slightly more forwards, bent more to the healthy side and the inclination of the pelvis was greater (Table 7).

Insert Table 7 here

Figure 3 presents moments of healthy subjects and amputees in hip, knee and ankle joints. None of the prosthetic knees excerts any moment during standing up.

Insert Figure 3 here

Discussion

Several studies have been done in recent years about transition from sitting to standing. The results of those studies are difficult to compare because their protocols, the initial positions of the subjects and the presentation of the results differ enormously. Most studies did not allow the subjects to use upper extremities (as was the case in the present study), however, some used backrests (Yoshida *et al.* 1983, Lundin *et al.* 1995). In addition, the initial knee angle varied from 75 to110 degrees of flexion and the feet position was different in almost each study. The present study only defined the seat height and the position of the upper extremities, otherwise the subjects were allowed to take their most comfortable position.

Also, the time that the subjects needed for standing up differs among the studies and the ranges of normal are very wide (Table 8). The control group in the present study needed a similar time as the healthy subjects in most above-mentioned studies (Table 8). In all studies, the subjects with impairments, with the exception of the subjects with low back pain (Coghlin *et al.* 1994), needed longer time to stand up. The trans femoral amputees in the present study needed the second longest time among all but still less than the healthy subjects in Kralj's study (Kralj *et al.* 1990) although they were slightly older than Kralj's subjects. None of the subjects in the present study were over 60 years but each took more time to stand up than the elderly subjects (Yoshida *et al.* 1983, Millington *et al.* 1992, Hughes 1996). They did not need significantly longer time from rising to the seat-off, but they did need significantly longer time from the seat off to standing (Table 3). Kotake *et al.* (1993) found in healthy subjects that the longer it took them to rise, the shorter the time to the seat-off and the longer the time from the seat-off to the maximum flexion of the hip joints while all other times did not change significantly.

Insert Table 8 here

Most studies assumed that there was symmetry in both lower extremities during standing up. Lundin *et al.* (1995) found that even in the healthy subjects there were differences in the peak joint moments between both lower extremities during standing up. In the present study, all healthy subjects except one did not have a significant difference in ankle, knee and hip joint angles at the time of the seat-off (Table 4) or in the force under both feet (Table 5), whereas the differences in these values in trans femoral amputees were much greater.

Standing up requires surprisingly large moments, particularly at the hip and knee (Fleckenstein *et al.* 1988, Roebroeck *et al.* 1994). The trans femoral amputees cannot and do not exert the knee moments on the side of amputation (Figure 3). Since none of the subjects in the present study had a myodesis of transected muscles acting around the hip, they might have had problems in exerting a great enough moment at the hip. Therefore, they had to find a compensatory mechanism, either mechanical (e.g. higher chair) or physical (e.g. different strategy of rising). This can be achieved by a different position of the body (Doorenbosch *et al.* 1994) or by different speed of standing up (Hughes *et al.* 1994). Full flexion of the trunk does not affect the motion of the knee and ankle, but does decrease the knee and the hip extension moments (Doorenbosch *et al.* 1994). It also increases the activity of the hip extensors, especially of the gluteus maximus muscle and the hamstrings, but in healthy there is also a co-contraction of the rectus femoris and vastus medialis (Doorenbosch *et al.* 1994, Roebroeck *et al.* 1994). The latest two muscles are cut in trans femoral amputees. Only a part of the gluteus maximus muscle, which inserts on the greater trochanter is not cut can give at least some of the required force. These findings also show that myodesis of muscles, specially biarticular ones, in trans femoral amputees is not only important for walking but may be even more important for standing up, the prerequisite for walking.

Hughes *et al* .(1994) described two strategies for standing up, the momentum transfer and the stabilization. In the momentum transfer a rapid forward motion of the trunk helps knee musculature to extend the knees. This seems an important strategy for trans femoral amputees who do not have myodesed knee extensors. In the stabilization transfer, the subject tries to shorten or eliminate the unstable phase by repositioning the center of the mass and base of support by sliding the buttocks forward, flexing at the hips and placing the feet back. Also, the stabilization is important for trans femoral amputees who have to prevent the passive prosthetic knee from flexing and collapsing during standing up. The present study has demonstrated that the trans femoral amputees used both strategies: they flexed the trunk significantly more than the healthy subjects at the time of the seat-off and they also flexed their hips to a higher extent, but they did not put the feet more backwards (Table 4). They needed slightly but not significantly longer time from the beginning to the seat-off (Table 3). By using both strategies they compensated for the lack of knee extensors which are the most active at the time of the seat-off (Roebrock *et al.* 1994). They also had to care about the stability of the prosthetic knee. This is probably the most important factor influencing the fact that they did not put more than 5% of the maximum weight on the prosthesis untill the knee was almost completely extended (Table 6). The differences in the prosthetic knee angle at the time of the 95% loading were small among the five measured subjects and the influence of the knee type did not seem to matter. However, to make any conclusions about the latter, a much larger number of subjects with different knee types will need to be measured. It will also be important to measure the EMG activity of different muscles during standing up. Stevens (Stevens *et al.* 1989) found that a preferred initial leg posture results in smaller magnitudes of head movement and ground reaction forces, decreased activity in trapezius and erector spinae but increased activity of quadriceps and hamstrings.

The results of the present study were limited by the small number of subjects and the difference in age between the healthy subjects and trans femoral amputees. Also, the EMG activity, which can provide important additional information, was not measured. However, in spite of those limitations, it can be concluded that standing up of trans femoral amputees was not symmetrical, they started to load the prosthesis when the knee was almost completely extended and their standing up was much slower. All this may indicate that trans femoral amputees can have severe problems when standing up. Elderly subjects who have undergone trans-femoral amputation due to vascular problems and have problems with walking can be expected to have even more problems with standing up than the subjects in the present study. The inability to stand up does not only severely limit the performance of daily activities but may also impose a great burden on carers. Prosthetic engineers may have to put more effort into the development of a prosthetic knee that will help trans femoral amputees to stand up more easily.

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Table 1

Subject	**Age (years)**	**Height (cm)**	**Body mass (kg)**	**Cause of amputation**	**Year after amputation**	**Stump length (cm)**	**Self-reported daily walking distance (km)**
A	46	179	85	Injury	25	25	1 - 2
B	55	172	90	Acute thrombosis	8	33	3 - 4
C	51	170	94	Cancer	33	28	10
D	28	194	80	Injury	8	23	1 – 2
E	49	177	77	Injury	32	20	5
F	24	192	67	Healthy			1-2
G	24	172	77	Healthy			1
H	29	174	65	Healthy			1
I	26	182	77	Healthy			1-2
J	26	173	74	Healthy			1-2

Table 2

Subject	**Shape of the socket**	**Knee**	**Feet**
A	Ischial containment	Hydraulic	Energy storing
B	Quadrilateral		Single axis
C	Quadrilateral	Hydraulic	Multi axis
D	Ischial containment	Polycentric (mechanical)	Single axis
E	Ischial containment	Single axis mechanical	Single axis

Table 3

Subject	**Time to seat-off (s)**		**Time from seat-off to standing (s)**		**Total time for stand up (s)**	
	Mean	SD	Mean		Mean	SD
A	0.89	0.116	1.81	0.187	2.70	0.235
B	1.56	0.204	2.36	0.209	3.95	0.348
C	0.64	0.019	1.08	0.074	1.72	0.072
D	0.83	0.146	1.90	0.239	2.73	0.163
E	0.67	0.033	1.30	0.097	1.97	0.124
Average	**0.918**	**0.375**	1.69	0.507	**2.62**	**0.868**
F	0.80	0.067	0.91	0.129	1.71	0.147
G	0.68	0.071	0.99	0.076	1.67	0.123
H	0.74	0.090	0.98	0.135	1.71	0.186
I	0.91	0.084	1.10	0.093	2.01	0.145
J	0.71	0.075	1.06	0.258	1.76	0.270
Average	**0.766**	**0.090**	**1.01**	**0.072**	**1.77**	**0.136**
p	**0.40**		**0.02**		**0.07**	

Table 4

Subject	**Ankle**				**Knee**				**Hip**				**Body angle**
	H	**P**	**D**	**p**	**H**	**P**	**D**	**p**	**H**	**P**	**D**	**p**	
A	108.8 ± 1.42	102.4 ± 1.37	6.4		87.5± 1.53	88.3± 1.86	-0.83		59.5± 1.76	54.9± 1.87	4.5		47.3 ± 2.2
B	114.1 ± 1.95	97.8 ± 2.77	16.3		89.2± 1.03	89.1± 3.38	0.1		64.0± 2.08	48.7± 2.54	15.3		49.0 ± 1.4
C	115.4 ± 0.71	98.4 ± 0.98	17.0		88.1± 1.02	95.7± 1.63	-7.7		73.3± 1.96	64.0± 1.99	9.3		41.7 ± 1.1
D	120.3 ± 1.34	97.4 ± 2.79	23.0		78.8± 1.29	95.7± 2.87	-16.9		67.6± 1.74	63.4± 1.28	4.2		42.7 ± 1.5
E	108.1 ± 0.75	92.5 ± 0.55	15.6		86.9± 1.24	102.3± 1.68	-15.5		60.3± 1.10	59.9± 1.15	0.4		45.5 ± 1.5
Mean	**113.3 ± 5.03**	**97.7 ± 3.53**	**15.7± 6.05**	**0.000**	**86.1± 4.18**	**94.2± 5.73**	**-8.1± 7.9**	**0.03**	**64.9± 5.70**	**58.2± 6.42**	**6.7± 5.73**	**0.12**	**45.2 ± 3.06**

F	116.2 ± .63	120.6± .91	4.4		84.0± 1.01	84.5± 1.09	-0.4		92.6± 1.90	88.5± 2.0	4.1		22.2 ± 2.3
G	122.0 ± 1.26	121.7± 1.53	-.4		88.3± 1.46	89.2± 1.85	-1.0		80.8± 3.77	82.4± 3.57	-1.5		38.8 ± 3.3
H	112.8 ± 1.02	114.1± .74	1.3		86.8± 1.86	87.2± 1.71	-0.5		74.2± 3.34	73.5± 3.23	0.6		36.9 ± 3.0
I	113.4 ± 2.63	113.4 ± 3.03	-.1		88.3± 2.45	87.2± 2.59	1.1		78.7± 3.63	77.6± 3.01	1.2		33.1 ± 3.2
J	115.4 ± 1.58	115.6± 1.67	0.2		84.3± 1.27	83.3± 1.03	1.0		74.3± 5.00	73.3± 4.61	0.9		35.7 ± 4.4
Mean	**117.1± 3.82**	**116.0± 3.65**	**1.1± 1.94**	**0.66**	**86.3± 2.04**	**86.3± 2.37**	**0.1± 0.93**	**0.97**	**80.1± 7.55**	**79.1± 6.44**	**1.1± 2.00**	**0.82**	**33.4 ± 6.59**
P	**0.23**	**0.000**	**0.001**		**0.90**	**0.02**	**0.05**		**0.007**	**0.001**	**0.07**		**0.006**

Table 5

Subjects	A	B	C	D	E	**Mean**	F	G	H	I	J	**Mean**
Maximal difference (left-right)	0.90	0.71	0.79	0.79	0.84	**0.81± 0.07**	0.02	0.22	0.00	-0.03	0.07	**0.05± 0.10**

Table 6

Subject	**Knee angle of the healthy leg**		**Prosthetic knee angle**		**Hip angle of the healthy leg**		**Hip angle on the amputated side**	
Time	1	2	1	2	1	2	1	2
A	80.3	91.4	154.9	179.2	70.6	61.2	130.3	163.8
B	79.9	91.4	175.4	177.1	91.8	65.7	132.8	168.9
C	79.2	94.7	148.5	163.9	76.3	78.5	135.8	158.9
D	71.1	85.4	176.6	179.3	79.1	73.3	163.6	174.9
E	81.2	87.9	158.6	172.9	68.3	60.3	141.0	176.7
Mean	78.3 ± 4.12	90.1 ± 3.59	162.8 ± 12.6	174.5 ± 6.5	77.2 ± 9.21	67.8 ± 8.00	140.7 ± 13.4	168.6 ± 7.4

Table 7

Subject	**Trunk angle in sagittal plane**		**Trunk angle in frontal plane**		**Trunk angle in transversal plane**	
	Mean	SD	Mean	SD	Mean	SD
A	53.0	1.6	9.2	2.6	8.4	2.1
B	52.1	2.5	8.8	3.0	10.5	1.9
C	42.5	1.5	9.3	1.2	10.5	0.7
D	44.3	1.7	6.3	2.3	11.0	2.4
E	49.3	1.7	10.1	1.2	4.7	1.6
Mean	48.2	4.7	8.7	1.5	9.0	2.6
F	22.5	2.2	1.0	0.4	2.3	0.7
G	41.6	5.0	9.9	1.9	8.3	1.1
H	40.7	4.1	2.2	1.0	3.4	1.1
I	34.3	3.3	2.4	1.4	5.0	1.2
J	36.4	5.0	1.3	0.4	3.9	1.0
Mean	35.1	7.7	3.4	3.7	4.6	2.3
p	0.01		0.02		0.02	

Table 8

Study	**No. of subjects**	**Age of the subjects**	**Diagnosis**	**Time for sit-to-stand (s)**
Yoshida 1983	10	27,9	Young male	1.34
	10	24.3	Young female	1.78
	10	67.4	Elderly female	2.06
	10	60.0	Hemiparetic due to cerebrovascualr accident	3.19
Fleckenstein 1988	10	25.4	Healthy	1.37
Kralj 1990	20	32.6 (24 – 51)	Healthy	3.33
Millington 1992	10	69 (65 – 76)	Healthy	2.03 (max. 2.54)
Coghlin 1994	5	20 – 45	Healthy	1.95
	5	20 – 45	Low back pain	1.70
Hesse 1994	20	43 (22 – 60)	Hemiparetic due to ischemia in the a. cerebri media or a. cerebri anterior	1.98
	15	41 (37 – 56)	Healthy	1.58
Roebrock 1994	10	27 (23 – 35)	Healthy	2.25
Kagaya 1995	12	26 (21 – 33)	Healthy	2.0
Hughes 1996	18	74.8	Moderate functional impaired elderly	2.44
Our study	5		Healthy	1.88

	5		Trans-femoral amputation	2.74

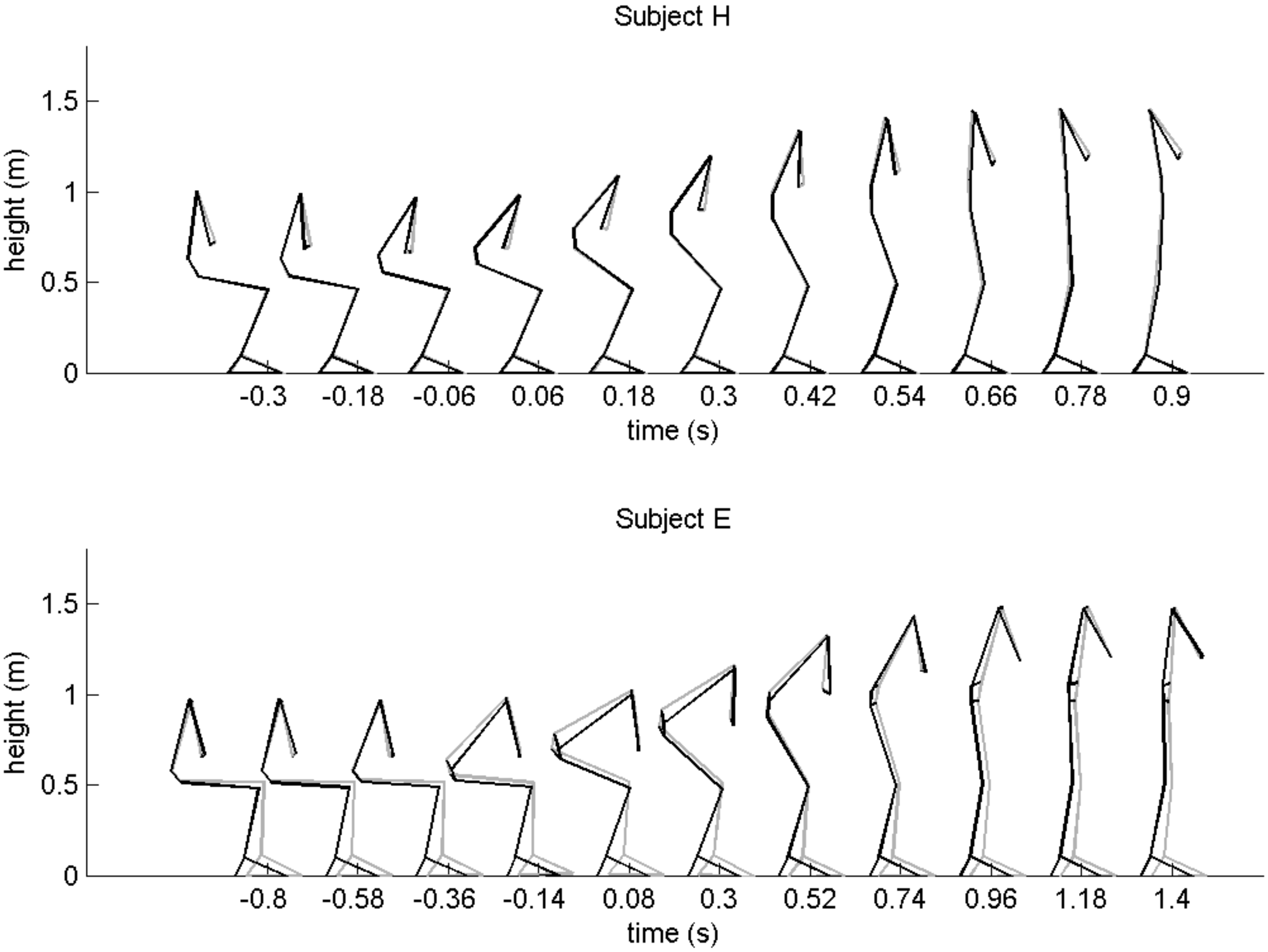
Subject H
height (m)
1.5
1
0.5
0
-0.3
-0.18
-0.06
0.06
0.18
0.3
0.42
0.54
0.66
0.78
0.9
time (s)
Subject E
height (m)
1.5
1
0.5
0
-0.8
-0.58
-0.36
-0.14
0.08
0.3
0.52
0.74
0.96
1.18
1.4
time (s)

Figure 1

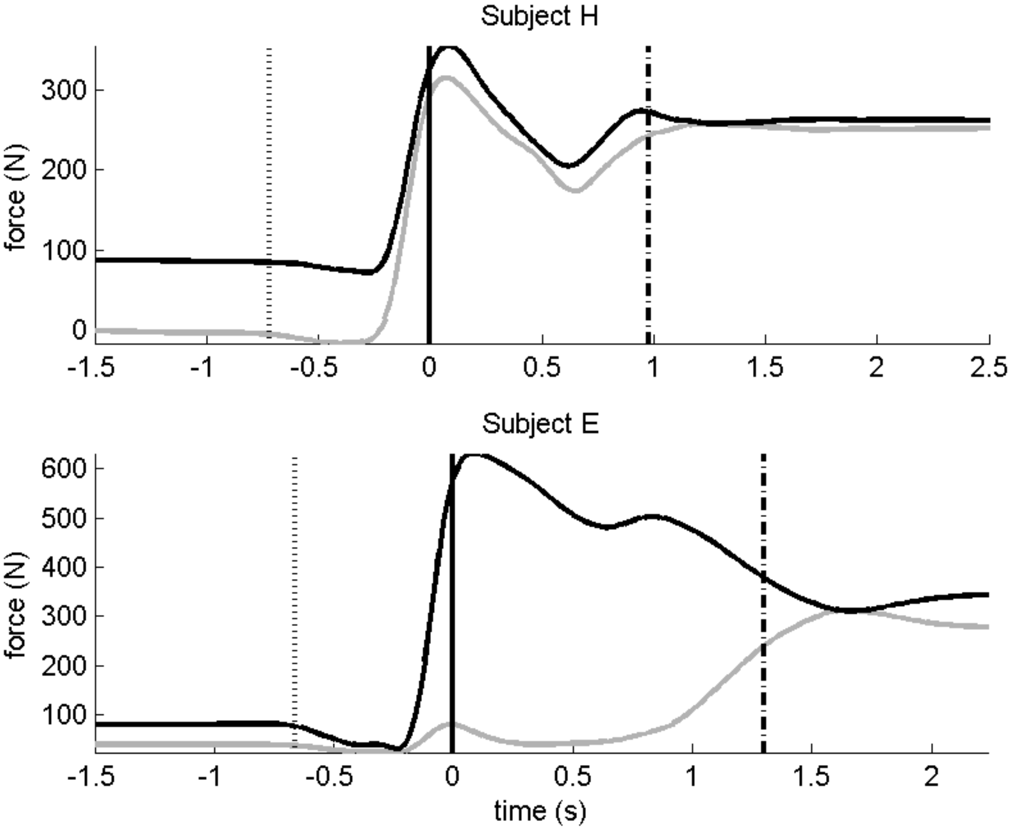
Subject H
force (N)
300
200
100
0
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
Subject E
force (N)
600
500
400
300
200
100
-1.5
-1
-0.5
0
0.5
1
1.5
2
time (s)

Figure 2

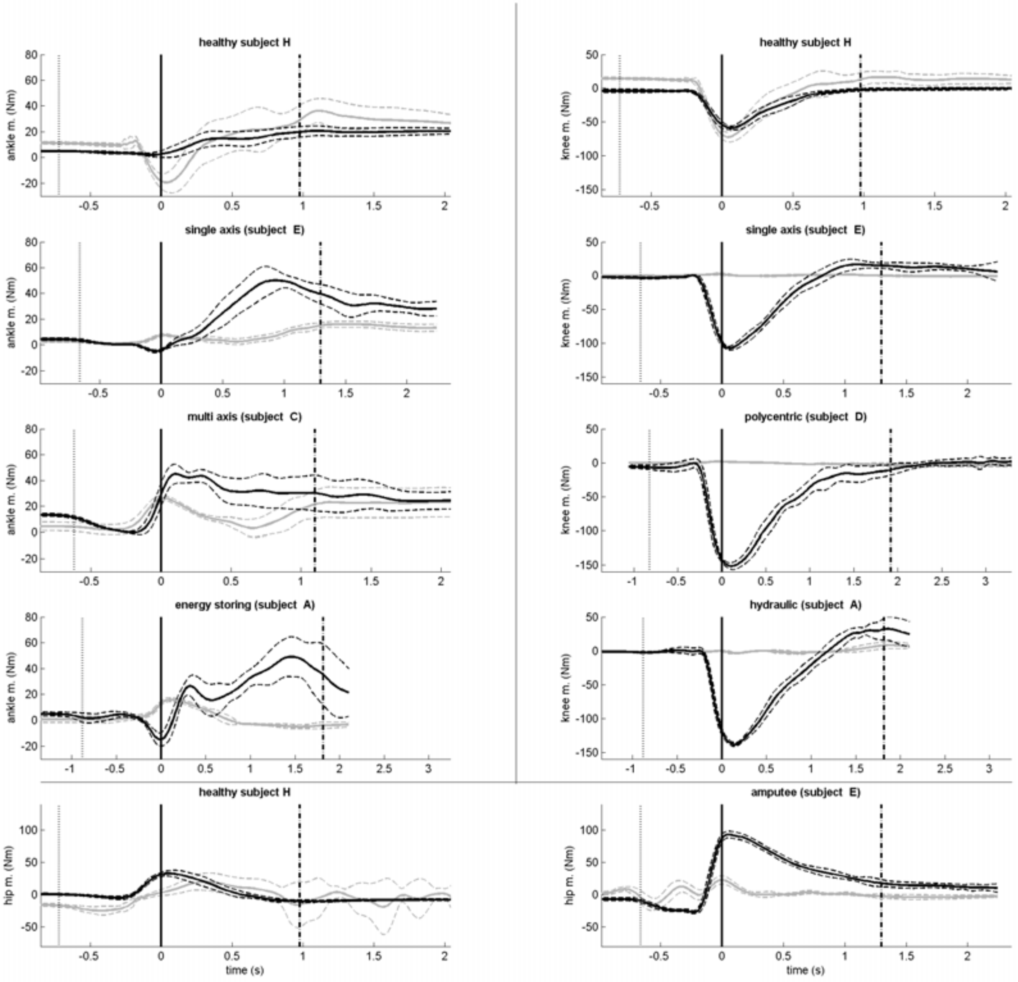
healthy subject H
ankle m. (Nm)
80 60 40 20 0 -20
-0.5 0 0.5 1 1.5 2
single axis (subject E)
ankle m. (Nm)
80 60 40 20 0 -20
-0.5 0 0.5 1 1.5 2
multi axis (subject C)
ankle m. (Nm)
80 60 40 20 0 -20
-0.5 0 0.5 1 1.5 2
energy storing (subject A)
ankle m. (Nm)
80 60 40 20 0 -20
-1 -0.5 0 0.5 1 1.5 2 2.5 3
healthy subject H
hip m. (Nm)
100 50 0 -50
-0.5 0 0.5 1 1.5 2
time (s)
healthy subject H
knee m. (Nm)
50 0 -50 -100 -150
-0.5 0 0.5 1 1.5 2
single axis (subject E)
knee m. (Nm)
50 0 -50 -100 -150
-0.5 0 0.5 1 1.5 2
polycentric (subject D)
knee m. (Nm)
50 0 -50 -100 -150
-1 -0.5 0 0.5 1 1.5 2 2.5 3
hydraulic (subject A)
knee m. (Nm)
50 0 -50 -100 -150
-1 -0.5 0 0.5 1 1.5 2 2.5 3
amputee (subject E)
hip m. (Nm)
100 50 0 -50
-0.5 0 0.5 1 1.5 2
time (s)

Figure 3

Table captions

Table 1: Description of subjects

Table 2: Prosthetic components of included subjects

Table 3: Times from the beginning of standing up to the seat-off, from the seat-off to standing and the total time to stand up (average for ten trials). P values indicate the comparison of mean values between the subjects after trans-femoral amputation and the healthy ones.

Table 4: Angles in the ankle, knee and hip joints on both sides (H – healthy, P- prosthetic), the differences (D) and the angle of the trunk at the time of the seat-off (average for ten trials).

Table 5: The maximal difference in force under both feet for the healthy subjects and the subjects after trans-femoral amputation in percentage of body weight (p= 0.001) (average for ten trials) Positive numbers indicate that the right leg was bearing more body weight than the left leg.

Table 6: The angles of the knee and hip joints at the time (1) when the force under the prosthetic (healthy) foot reached 5% of the maximal force under that foot and at the time (2) when the force under the prosthetic (healthy) foot reached 95% of the maximal force under that foot (p=0.000 between healthy and prosthetic knee/hip and prosthetic knee/hip on the amputated side for both times) (average for ten trials).

Table 7: The maximal trunk angles (degrees) in all three planes during standing up (average for ten trials).

Table 8: The time that the subjects needed to stand up in various studies

Figure captions

Figure 1: Standing up of a healthy (H) subject and a subject after left trans-femoral amputation (E) in the sagittal plane. While standing up of the healthy subject was symmetrical, the subject after left trans-femoral amputation positioned the prosthesis more forwards than the healthy leg and rotated the trunk backwards to the left side (left – gray, right – black line).

Figure 2: Loading of the left (gray line) and the right (black line) forceplate during standing up of a healthy (H) subject and a subject after left trans-femoral amputation (E). The first vertical line marks the beginning of the standing-up manoeuvre, the second the time of the seat-off and the last the occurrence of the quiet standing as defined in the method section.

Figure 3: Moments in hip, knee and ankle joints of healthy subjects and amputees.