Gait re-education in transfemoral amputees The training programme, gait analysis, oxygen consumption and coping

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Contents

List of publications

This dissertation is based on the following papers, which are referred to in the text by their Roman numerals. Papers I, II, III, V have been reprinted with kind permission from the publishers.

I Sjödahl C, Jarnlo G-B, Persson BM. Gait improvement in unilateral transfemoral amputees by a combined psychological and physiotherapeutic treatment. J Rehab Med 2001; 33, 114–118.

II Sjödahl C, Jarnlo G-B, Söderberg B, Persson BM. Kinematic and kinetic gait analysis in the sagittal plane of trans-femoral amputees before and after special gait re-education. Prosthet Orthot Int 2002; 26: 101–112.

III Sjödahl C, Jarnlo G-B, Söderberg B, Persson BM. Pelvic motion in trans-femoral amputees in the frontal and transversal plane before and after special gait re-education. Prosthet Orthot Int 2003; 27: 227–237.

IV Sjödahl C, Thorsson O, Jarnlo G-B, Persson BM, Wollmer P. Oxygen consumption in transfemoral amputees during walking before and after special gait re-education. (submitted)

V Sjödahl C, Gard G, Jarnlo G-B. Coping after trans-femoral amputation due to trauma or tumour—a phenomenological approach. (Accepted in Disability and Rehabilitation 15 December 2003).

Definitions and abbreviations

A conscious therapeutic approach several techniques to create a therapeutic alliance by use of e.g. meeting the patient with empathy and respect, giving warm mental support, using precise framework and keeping regular contact.

Avoidance the act or practice of keeping away from or withdrawing from something undesirable (Merriam-Webster Medical Dictionary, Medline Plus)

Body-image a concept, which originates from Schilder (1970), referring to the three–dimensional image of our body that we have of ourselves.

Coping cognitive, emotional and behavioural efforts to keep a balance between a person and the environment (Folkman and Lazarus, 1985).

Energy cost of walking the rate of oxygen consumption related to the gait speed, O_2 ml × kg^{-1} × m^{-1} (Waters and Mulroy, 1999).

Denial a psychological defence mechanism in which confrontation with a personal problem or with reality is avoided by denying the existence of the problem or reality (Encyclopaedia Britannica).

Downward comparison making comparisons with more unfortunate persons (Taylor et al., 1983).

Gait cycle the equivalent of one stride, consisting of a stance and a swing phase. In all the figures, the x-axis represents one gait cycle starting with heel-strike at 0 percent.

Holistic relating to or concerned with wholes or with complete systems rather than with the analysis of, treatment of, or dissection into parts; ***holistic*** in medicine attempts to treat both the mind and the body (Encyclopaedia Britannica)

ICF International Classification of Functioning, Disability and Health. WHO, Geneva 2001.

ISO	International Standards Organization, ISO 8548-2. Method of describing lower limb amputation stumps. Geneva, 1993.
Kinematics	describes the details of the movement itself without being concerned about the forces that cause the movement (Winter, 1990).
Kinetics	includes both internal and external forces. Internal forces come from muscle activity, ligaments or from friction in the muscles and joints. External forces come from the ground or from external loads (Winter, 1990).
Moment	Turning effect of a force about a point; the product of the force and the perpendicular distance from its line of action to that point (Winter, 1990). Internal moments were calculated and interpreted as muscles and ligaments counteracting the external moments produced by ground reaction force (Gage, 1991).
Oxygen consumption	the rate of oxygen consumed per kg; O_2 ml × min^{-1}× kg^{-1} (Waters and Mulroy, 1999).
Power	calculated as the product of joint net moment and joint angular velocity (Gage, 1991).
Repression	a process by which unacceptable desires or impulses are excluded from consciousness and left to operate in the unconscious (Encyclopaedia Britannica).
RQ	abbreviation for the respiratory quotient, which is the ratio of the volume of carbon dioxide given off in respiration to that of the oxygen consumed (Merriam-Webster Medical Dictionary, Medline Plus).
Vaulting	raising the entire body by early and excessive plantar flexion of the intact foot to obtain foot-clearance (Berger, 1992).

Abstract

A gait re-education programme, combining physiotherapy with a psychologically conscious therapeutic approach, was applied to nine unilateral transfemoral amputees, whose amputation was caused by trauma or tumour. The participants trained once a week for a mean 10 months. The median age was 33 years (range 16–51). They had worn a prosthesis for more than 18 months and had completed conventional rehabilitation. Before treatment, walking ability was limited and three used walking aids. All had problems with low-back pain. The effects of training on gait pattern and gait speed were evaluated with a three-dimensional motion analysis system. Oxygen consumption and energy cost were measured by analysing expired gas and heart rate was measured by electrocardiogram. Semi-structured interviews were performed to describe coping strategies in the acute phase and over time.

Results showed normalized gait speed comparable to healthy non-amputees of similar age, due to improved gait technique and walking skills. After treatment none needed walking aids and almost all low-back pain had disappeared. In addition, seven participants learnt to jog. Results indicate that this new approach may add skills, mostly on participation level, for leading a relatively normal life. The positive results remained at a six-month follow-up. The participants' strategies for coping in the acute phase were denial and avoidance. Over time they used downward comparisons, positive comparisons and repression. Only one participant had fully accepted the situation and adjusted to the new norm. Future research will show whether these results can be generalized in a controlled study.

Summary in Swedish
Sammanfattning på svenska

Syftet med avhandlingen är att beskriva och utvärdera en behandlingsmetod, som avser att öka gångförmågan hos lårbensamputerade. Metoden, vilken tidigare inte är prövad för den här gruppen patienter, kombinerar sjukgymnastiska metoder, huvudsakligen använda inom psykiatrin, med vedertagna ortopediska och biomekaniska behandlingsprinciper. Den syftar till att öka kroppsmedvetenheten och att integrera protesen i den amputerades nya kroppsbild och i rörelse. I behandlingsmetoden ingår att behandlaren använder ett medvetet och aktivt förhållningssätt för att analysera, motivera och engagera patientens egna resurser. Att åter lära sig att gå och röra sig obehindrat betraktas i metoden som en process, vilken kräver tid. Behandlingstiden har varit tio månader i genomsnitt, vilket motsvarar mindre än halva kostnaden för en ny protes.

Under 1994–1995 tillfrågades samtliga patienter inom Helsingborgs och Lunds sjukvårdsdistrikt med lårbensamputation och benprotes till följd av tumör eller trauma. Fem män och fyra kvinnor deltog i studien. Medianåldern var 33 år (16–51) och medianen för den tid de hade brukat sin protes var 6,5 år (3–27). Före träning gick deltagarna långsamt, med vaggande gång och hade svårt att använda sin protes på ett ändamålsenligt sätt. Tre deltagare använde gånghjälpmedel. Den som bäst behärskade sin protes orkade gå ca 500 m innan han behövde vila sig, men de allra flesta klarade bara av att gå 100–200 m. Samtliga hade sekundära besvär i form av ländryggssmärtor.

Resultatet av behandlingen visade att gånghastigheten normaliserades till den hos friska personer i motsvarande åldersgrupper. Gångmönstret, utvärderat med tredimensionell gånganalys, visade ett ökat arbete på den amputerade sidan, vilket gav en ökad symmetri i höfterna sett från sidan. En ökad bäckenrotation uppmättes troligen som ett resultat av ökad steglängd. Framifrån sågs rörelser som antingen tydde på en kompensation för svaga abduktorer eller en svårighet att stabilisera proteshylsan. Bäckenets ökade rörelseomfång sett framifrån uppstod troligen på grund av mjukdelsrörelser då lårbenet trycktes ner respektive lyftes ur hylsan under gång. Efter behandling minskade energikonsumptionen när deltagarna gick med sina självvalda nya snabbare gånghastigheter, medan syrekonsumption och hjärtfrekvens ökade. Dessa resultat visade att deltagarna inte förbättrat sin kondition utan snarare ökat sin egen förmåga och blivit tekniskt skickligare att gå med sin protes. Sju deltagare lärde sig till och med att springa och nästan all ländryggssmärta var borta. De positiva resultaten kvarstod vid uppföljningen efter sex månader.

I och med den förbättrade förmågan vågade deltagarna också att pröva andra, mer socialt betydelsefulla aktiviteter. De vågade vara ute i trängsel bland andra människor på stan med risk för att bli knuffad och några handlade till exempel kläder själv för första gången på flera år. De gick på utomhuskonserter och gick ut och dansade och upplevde dessutom att de hade roligt när de gjorde det. Deltagarna upplevde därigenom en känsla av ökad livskvalitet och ökat välbefinnande.

Den del av avhandlingen som rör de amputerades psykologiska förmåga att hantera sorgen efter ett amputerat ben visade att deltagarna huvudsakligen använde förnekande och undvi-

kande i den akuta fasen. Efter hand använde de alltmer strategier som jämförelser i nedåtgående riktning och positiva jämförelser. Endast en deltagare i studien hade fullt ut anpassat sig och accepterat sin situation.

Introduction

Lower limb amputees, even with a modern prosthesis, walk with a more or less limping gait and reduced speed. With a higher amputation level this effect is even more evident. For transfemoral amputees, even with a good femoral stump, the problem is considerable.

The gait-pattern of transfemoral amputees is asymmetrical, with shorter stance phase and longer swing phase on the prosthetic side (Boonstra et al., 1994), and stance phase increases with decreasing residual limb length (Jaegers et al., 1995a). There is often lateral trunk bending over the amputated leg because of weak hip abductors and lack of stabilization from the socket (Berger, 1992; Jaegers et al., 1995a). Vaulting by heel-rise on the healthy leg is often used to secure foot clearance in the swing of the prosthetic side (Berger, 1992; Czerniecki, 1996), which may add to increased vertical displacement resulting in increased energy cost. The muscles directly controlling the knee joint are lacking and functional restrictions of the prosthetic knee joint may also contribute to the higher energy cost (Jaegers et al., 1993). Jaegers et al. (1995b) also showed atrophy of both cut and uncut hip muscles.

Gait analyses by observational assessments have been done for years by physiotherapists and doctors in their clinical work (Toro et al., 2003). Other established methods have been using an electrogoniometer (Olsson et al., 1986) or two-dimensional computerized systems (Winter, 1990). In 1994, a three-dimensional VICON system was installed in Lund, which made it possible to measure movements in the transverse plane as well. Since then there has been a lot of continuous development, not only in the hardware and the software, and studies, although not yet published, were conducted in the gait laboratory in order to obtain reliable data and interpretations. The interpretation of the kinematic and the kinetic data is done together with clinical and observational assessments, described by Gage (1991) and Stout (1995).

Energy cost of walking can be calculated by relating the rate of oxygen consumption to the gait speed. This is considered to be the most appropriate measurement to compare gait efficiency between individuals (Bard and Ralston, 1959; Waters et al., 1976; Fisher and Gullickson, 1978; Waters and Mulroy, 1999). Thus measured, the energy cost of walking is higher in amputees than in healthy individuals and increases with higher levels of amputation (Waters et al., 1976; Fisher and Gullickson, 1978; Huang et al., 1979; Waters et al., 1989). These findings indicate that amputees choose a much slower comfortable gait speed than healthy non-amputees, so that the mean rate of oxygen consumption will not exceed the normal rate (Waters and Mulroy, 1999).

According to the national Swedish register of medical diagnoses and surgical procedures, 2440 lower limb amputations were performed in 2001. Of these 680 were transfemoral, i.e. at above knee level. Only 31 of these patients were below the age of 60 (Socialstyrelsen, MARS, 2003). In this group a majority was due to trauma or tumour, whereas lower limb amputations in general were caused by vascular disease in about 90% of the cases (Eneroth, 1997).

The most extensive and thorough description of physical rehabilitation for amputees in Sweden is by Wahlborg-Kamwendo (1979). It is still used in physiotherapy education and in clinical applications and describes physical training from very early stages after amputation to more advanced gait training. The Roehampton model (Engstrom and van der Ven, 1993) is another model often cited, and these two models agree quite well with each other in terms of exercises and how the treatment is performed. Treatment aims at a basic level of functioning to maintain activities of daily living. Other authors are also in accordance with the models stated above (Ham, 1996; Edelstein, 1996). Advanced training and running patterns in transfemoral amputees have been described by Mensch and Ellis (1986) and Mensch (1993b). Mensch (1990; 1993a; 1993b) stresses weight-bearing exercises and functional movements and skills. This training programme also includes co-ordinated arm movements and spinal rotation to improve balance and postural control. Another method used is proprioceptive neuromuscular facilitation resistive gait training; compared to traditional treatment, this has been shown to increase the symmetry of the step lengths between the amputated and intact side due to increase in weight-bearing percentage on the amputated side. There was, however, no improvement in the gait speed (Yigiter et al., 2002).

These training programmes and techniques do not explicitly include taking care of psychological problems following severe body injury and loss of a limb caused by trauma or tumour. All models of amputee rehabilitation referred to above describe patients feeling psychologically unstable when facing the consequences of amputation and all put emphasis on using an empathic approach. It is also suggested to help the patient to accept the amputation and the altered body image to be able to adjust to the prosthesis (Wahlborg-Kamwendo, 1979; Engstrom and van der Ven, 1993). However, there is no description of how this is achieved or what technique to use. In this thesis, the emotional reactions and the psychological aspects of the loss and the trauma serve as guidelines to understanding what coping strategies are available, the representation of the loss, how the rehabilitation is to be structured to integrate the prosthesis in the movements and the body image.

The concept of body image originates from Schilder (1970), who refers to the three-dimensional image of our body that we have of ourselves. Schilder was interested in the representation of the body in the brain and studied several patients with neurological and other lesions. One example was an amputee who suffered from phantom sensation and pain from the lost limb and forefoot. This patient later had a stroke and these sensations disappeared. From this study Schilder concluded that all parts of our body are represented in the brain and started to form the concept of body image still used today.

According to Schilder (1970), body image consists of schemata, which are constructed by sensory-motor perception, but emotional processes constitute the power and the source of energy, guiding them. The great variation in perceiving a phantom limb can therefore only be understood by taking into account the emotional reactions an individual has towards his/her own body (Schilder, 1970). When we are concerned with our own body we often have an emotional attitude. This perspective has been further developed within physiotherapy, mostly used in psychiatric treatment (Mattsson and Mattsson, 1994; Mattsson et al., 1997; Lundvik Gyllensten et al., 1999). A body hosts emotions within muscular tensions that are connected to memories both pleasant and unpleasant (Mattsson and Mattsson, 1994; Mattsson et al., 1997; Lundvik Gyllensten et al., 1999). When treating the body physically as health personnel, we must also expect and be prepared for emotional or vegetative reactions. Muscular tensions may conceal unconscious material and therefore the patient and the personnel are unprepared for these unexpected reactions, which may seem frightening.

According to Merleau-Ponty (1989) we use our body as a tool to investigate other objects, to walk around, observe and even carry other objects around. Thereby our body differs from other objects, as it may be used as a tool to communicate with the world. The moving body cannot be compared to other moving objects. I don't have to look for it, because it is always with me. The relation between my body and the decision to move is a unity. If our body is our instrument to assess the world, then we understand that every change in the body also changes our access to the world. Dramatic changes occur with illness and injuries to the body. Merleau-Ponty (1989) describes how we may compensate by using different objects, thereby expanding our body sphere. The most famous example given by Merleau-Ponty (1989) is the blind man with his stick. The stick itself has ceased to be an object to the blind man and is not even conceived of as being separated from the body. Its point has turned into a sensitive area, compensating for the lost sight.

In the thesis, this perspective is used when integrating the prosthesis with the body sphere and body image. The prosthesis by itself may be regarded as an object just like a lamp or a chair. It is not until it is integrated as a part of a movement that it also becomes an extension to the body sphere and, properly trained, the individual may develop increased sensitivity for the inputs through it. There are specific qualities of the skin, which separates us from other objects and is also a sensory organ, which helps in perceiving the qualities of the outside world (Merleau-Ponty, 1989). If my right hand touches my left hand, I can feel the touch of one hand and at the same time feel the quality of the other by the examining hand (Merleau-Ponty, 1989). Schilder (1970) also sees the skin as defining ourselves in relation to other objects. We don't get a clear image of the body when resting. It is when we are moving and in relation to other objects and the outside world that we perceive our body (Schilder, 1970).

To move or to do an exercise does not necessarily mean that you are aware of what you are doing, according to Feldenkrais (1988). Exercises should therefore be constructed in order to raise the awareness and promote the participant to think while performing (Feldenkrais, 1988). Bergland (1994) also explains that motor learning should be done by practice and active problem-solving with great variation instead of repetitive exercises. To be able to develop skills is to develop the ability to use and take advantage of perceptual information to co-ordinate movements and postural control in a flexible way. In this way the individual acquires conscious control and a full range of different strategies. Being able to repeat just the same exercise stimulated only the short-term memory, according to Bergland (1994). But if the context is changed, the capacity for problem-solving is stimulated, which in turn results in long-term learning.

The relatively young amputees, whose amputation was caused by trauma or tumour, are usually healthy in all other respects. They will have to learn to live with the prosthesis for many years to come. When they have been provided with their prosthesis and the standard rehabilitation is finished, they are therefore expected to return home to lead a fairly normal life. However, the non-vascular transfemoral amputees have been shown to have considerable problems related to the amputation and the prosthesis. Hagberg and Brånemark (2001) studied 97 subjects, aged 22–69, and showed that the amputation had had a considerable impact on quality of life, with 25% considering themselves to have a poor or extremely poor overall situation. Further, Hagberg and Brånemark (2001) showed that 61% were unable to walk in woods or fields and 59% were unable to walk quickly. To enable the transfemoral amputee to adjust to the new situation both physically and psychologically, a holistic perspective is needed in the rehabilitation model.

Objectives

General

The general aims of this thesis are to describe the principles of a gait re-education programme tested on transfemoral amputees, combining methods in physiotherapy with a conscious therapeutic approach, and to evaluate the effects of such training.

Specific

- To describe the theories and the structure of the training programme, the training procedures and the use of a conscious therapeutic approach.
- To measure the effects of training on gait technique and gait pattern in different anatomic planes before and after treatment and at a follow-up after six months. The aim was also to compare the values from the intact leg with those from the amputated leg and from a healthy reference group.
- To describe the effects of the gait re-education programme at various speeds by means of oxygen consumption, heart rate, respiratory quotient, energy cost of walking and capillary blood lactate concentration measured before and after treatment and at a follow-up after six months.
- To describe how relatively young transfemoral amputees, whose amputation was caused by trauma or tumour, experienced their amputation retrospectively and their coping strategies in the acute phase and over time. The aim was also to describe the unique experience of each participant and whether the circumstances that had led to the amputation might have added to the way in which the participants perceived their situation.

Participants

The transfemoral amputees

Between 1994 and 1995, we invited all patients aged 16–60, living within the health-care districts of Helsingborg–Landskrona–Lund in south-west Sweden, who had had a unilateral transfemoral amputation caused by trauma or tumour and who had become prosthetic users. All had to understand written and spoken instructions in Swedish. They had to have been fitted with a prosthesis at least 18 months previously and to have completed standard rehabilitation. Exclusion criteria were amputation caused by diabetes or vascular disease and general diseases limiting gait.

Sixteen persons met the criteria. Three men and four women (mean age 38, range 19–51) were excluded, one for medical reasons, one for failing to participate in treatment on a regular basis because of his working situation, and three because they died before the start of treatment. Two participated only in the interview that preceded treatment and they are included in paper V. Both interrupted treatment, one because of an altered family situation and the other because his office was moved.

Five men and four women completed the treatment and follow-up. The amputation was caused by tumour in one man and four women. Two men had been in motorcycle accidents and two had been injured at work. All had been amputees since a median 6.5 years (range 3–27) and had worn their prosthesis for more than 18 months. The median age was 33 years (range 16–51) (Table 1). The prosthetic components and stump lengths were measured according to ISO standard (1993) (Table 2). All had completed a conventional rehabilitation and were considered stable in their prosthetic use. One had a half disability pension and the others

Table 1. Description of transfemoral amputees (N=9) and the reference group (N=18), M = male, F = female.

Transfemoral amputees (N=9)					Reference group Female (N=9)			Reference group Male (N=9)		
Gender M/F	Age (y)	Height (cm)	Body weight (kg)	Years of amp (y)	Age (y)	Height (cm)	Body weight (kg)	Age (y)	Height (cm)	Body weight (kg)
F	16	158	51	5	33	167	79	21	181	68
F	34	160	66	16	34	166	54	37	173	73
F	49	160	62	4.5	25	170	65	28	192	89
F	51	167	82	27	37	171	82	47	173	68
M	40	191	67	13.5	38	160	64	36	172	71
M	28	186	68	7.5	52	155	54	31	184	78
M	24	185	78	6.5	50	160	61	26	186	85
M	33	190	106	3	38	172	59	35	187	93
M	23	179	64	4.5	43	176	68	34	183	96
Mean	33	175	71	9.7	39	166	65	33	181	80
Median	33	179	67	6.5	38	167	64	34	183	78
Range	16–51	158–191	51–106	3–27	25–52	155–176	54–82	21–47	172–192	68–96

Table 2. Stump length, socket and prosthetic components in nine transfemoral amputees.

Case n:o	Stump length ISO standard*	Socket	Knee	Foot +
1	average	ischial containment	Total knee mechanical	Seattle foot
2	short	quadrilateral	Aqua pend pneumatic	Flex foot
3	short	quadrilateral	Total knee mechanical	Flex foot
4	average	quadrilateral	Total knee mechanical	Multiflex Ankle Seattle foot
5	long	quadrilateral	Växjö knee hydraulic	Multiaxis Växjö foot
6	average	Ischial containment	Mauch knee hydraulic	Flex foot
7	long	quadrilateral	T-Ling pneumatic	Flex foot
8	average	quadrilateral	Aqua pend pneumatic	Flex foot
9	average	ischial containment	Aqua pend pneumatic	Flex foot

* short means length less than width at the base, long means length more than twice the width at the base and average means stump length between 1–2 times the width at the base of stump (ISO standard, 1993).
+ all prosthetic feet are energy-storing

were working or studying full-time. To avoid confounding factors, all kept their prosthesis (Table 2) throughout the study, but the prostheses were serviced and worn-out parts were replaced. No socket or alignment changes were made during the study. All gave their informed consent and the study was approved by the ethics committee.

Motor function and perception of the prosthesis before the gait re-education (paper I)

All participants were community dwelling and managed well indoors. Two amputees used one stick and one used two crutches before treatment. Although the participants differed in many ways, e.g. regarding age, years of wearing a prosthesis, cause of amputation, they all had a similar gait pattern at the first evaluation. This pattern included imbalance of body weight towards the intact side, in standing as well as walking, which suggested an impaired body awareness and a poor awareness of the amputated side, which seemed to have been disconnected from awareness of movement.

A major part of the movement energy was focused on lifting/swinging the prosthesis forward with a kicking-like movement, i.e. using pull-off instead of push-off and at the same time use vaulting on the intact side, i.e. lifting the body by heel-rise on the intact side. The effort and the movement energy were directed upwards. Thereby information from proprioception in the amputated leg was assumed to be reduced and further, the participants were unable to take advantage of the energy-storing function of the prosthetic foot. Also the whole body weight was carried and balanced by the forefoot of the intact leg during a major part of stance-phase, which made the participant vulnerable to external factors, for example wind or surrounding people. Even the slightest push would throw him/her off balance.

The prosthesis was used mainly as a support, similar to a cane. Stance-phase was shorter and step length was longer on the amputated side than the intact side. During swing-phase on the amputated side they bent the trunk laterally towards the intact leg and during stance-phase towards the amputated side, creating a double limping. On even and hard ground, the whole group walked with their heads bent down and carefully observed the ground to detect any danger such as holes or bumps. When the surface changed from asphalt to sand the pathological gait pattern was more pronounced, which created balance problems. They all expressed discomfort and uneasiness when walking on a soft surface, since they were unable to feel the position of the prosthetic foot in relation to the rest of the body.

Co-ordination between upper and lower body was poor. Turning around in a safe way was possible only towards the intact side. Everyone lost their balance and almost fell when asked to continue walking and at the same time turn the head and shoulders, as you do when taking a quick glance over the shoulder. Losing balance included more than being able to walk without falling. They all managed well indoors, but reported fear of being pushed and losing their balance in crowds. Therefore most of them had avoided going shopping, or to outdoor concerts and market places or any other social event that meant being in a crowd, since they were amputated. Although it was a young group, basic things like being able to walk out of doors was not a natural and normal thing to do. Most of the participants had not been to a recreation area, such as a beach or a wood, for several years, in some cases since the amputation.

All participants expressed feelings of discomfort about the prosthesis. It galled their skin, did not co-operate, was heavy and could not be trusted since it sometimes broke down or the knee joint could suddenly let go. The best thing of the whole day was to come home and take it off, was the common opinion.

Everyone reported low-back pain almost every day and very often to a degree that stopped them from carrying out their daily plans. It was described as stabbing when moving and aching while resting.

The reference group

For the gait analyses (papers II and III), a convenient sample of healthy volunteers, nine men and nine women, was chosen among hospital employees as a reference group with a mean and median age of 36 years (range 21–52) (Table 1).

Methods

The gait re-education programme (paper I)

Theories and structure

The asymmetry of movements and the prosthesis not being used in a functional way, but seeming to be excluded from the awareness of body and movement of the participant, was interpreted as a form of denial. Therefore it was assumed that merely verbally pointing out the asymmetry of the movements or using traditional physiotherapy aiming to correct posture (e.g. by using a mirror), would not be sufficient to change the inability to integrate the prosthesis. This assumption was based on theories of physiotherapy mostly developed within psychiatric care, where muscular tension and imbalance in posture can be interpreted as a muscular defence, when an individual is put under psychological stress (Feldenkrais, 1988; Mattsson and Mattsson, 1994; Mattsson et al., 1997; Lundvik Gyllensten et al., 1999). Therefore physiotherapy, mostly used in psychiatry, was used aiming to increase body awareness and integrate the prosthesis in a more functional way. In the treatment programme, several theories on body awareness were combined, originating from Swedish psychiatric physiotherapy. Exercises and movement were combined and used to activate the centre line and retain it while moving in order to maintain and keep a proper alignment (Mattsson and Mattsson, 1994; Mattsson et al., 1997; Lundvik Gyllensten et al., 1999), to work in diagonals (Feldenkrais, 1988), to integrate respiration in a functional manner (Feldenkrais, 1988; Mattsson and Mattsson, 1994; Mattsson et al., 1997) and also to use very simple exercises to build movement sequences. None of the theories were especially emphasized, but their mutual philosophy, that inner balance is brought about by balance in posture and muscular tone, was the guideline. Exercises were picked and used based on individual needs and were individually adjusted. The structure of the gait re-education programme is shown in Fig. 1.

The participants had been walking with an asymmetrical gait pattern for many years. It was therefore necessary to re-educate them indirectly, as they were not aware of this imbalance in posture and movements. One technique to use to raise the awareness is to give feedback as questions instead of statements, i.e. “Where are you working now? Which muscles are active?” In this way the participants were forced to be aware of a movement they did every day but not consciously. In the beginning the participants started with very simple movements, i.e. shifting body weight in different standing positions. The exercises were shown to the participant who then imitated the therapist. Without verbal corrections the participant had to discover the movement and the variations in the performance. This discovery is an individual process and cannot be hastened (Feldenkrais, 1988; Mattsson and Mattsson, 1994; Mattsson et al., 1997). When the awareness of the movement increased, the intensity and difficulty were also increased. For example, one exercise started and while performing this exercise, another exercise was shown by the therapist and added to the first. This not only raises the level of awareness but also influences the participant to think while acting and act while thinking (Feldenkrais, 1988).

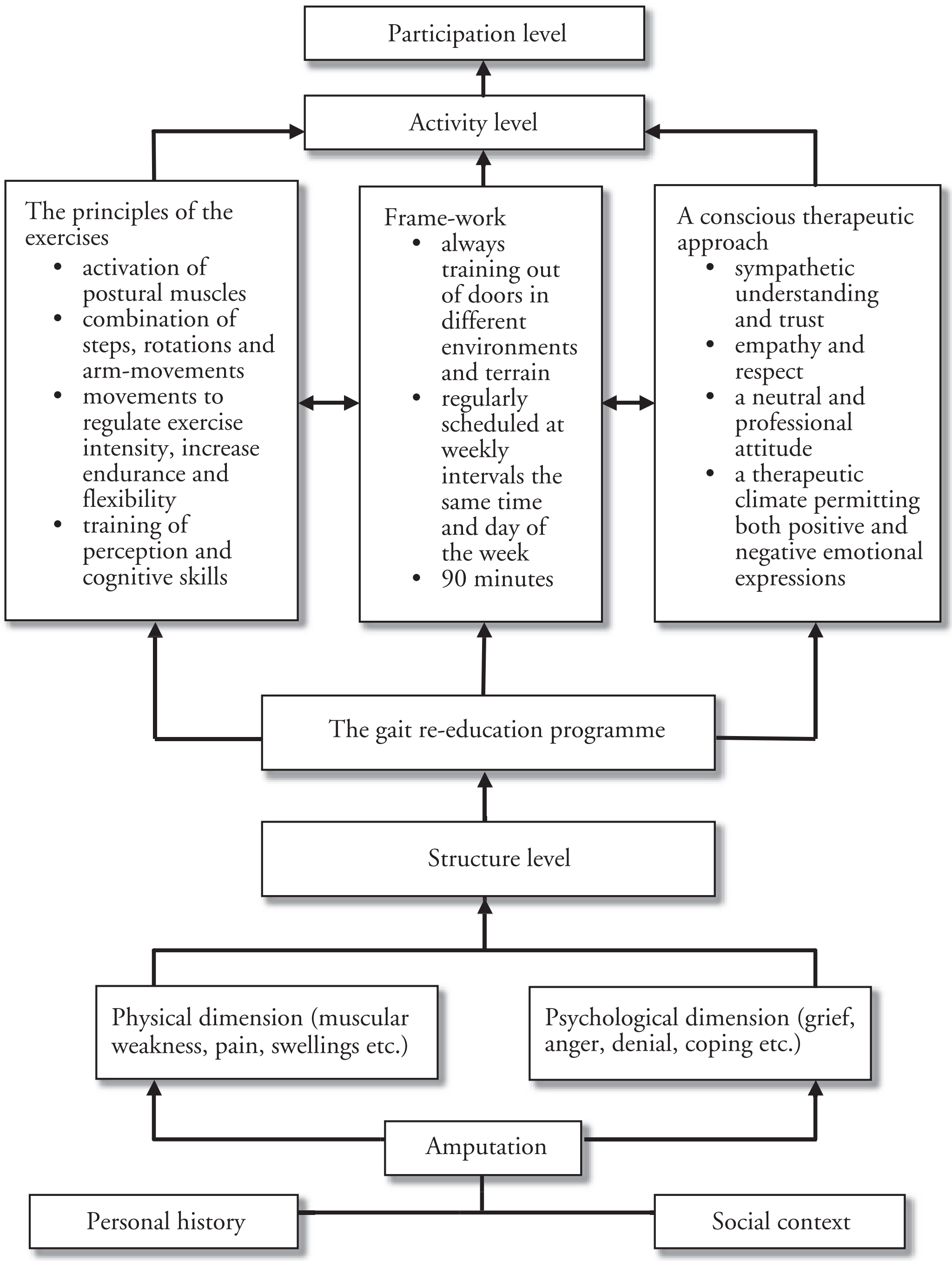


Fig. 1. The gait re-education model

Every session had a key sentence, e.g. “Focus on your hip extensors while extending your hip and pushing off.” This was not a task, but a key to improved performance. It was not even explained. The therapist sometimes noted improved skill before the participant, who in turn maybe two sessions later started the session by saying, "I know now what you mean by extending the hip, since I now notice when I walk the wrong way." In this situation the therapist could say, "Yes, I have noticed that you are performing much better, than when we started." This answer implies that results can be better yet and more work is required. The participants reported that the feeling that their functioning could be further improved was an important motivating factor in the treatment and training.

The lateral bending of the upper body probably served to reduce the hip-joint moments and at the same time transfer the centre of mass (COM) over the base of support. Thereby the criteria for stability have been fulfilled, although the ability to be flexible is hereby substantially reduced (Hirschfeld, 1991). Hirschfeld (1991) states that the interpretation of inputs is done in accordance with what the individual has experienced and the central set of the subject, i.e. the ability within the central nervous system to prepare the motor system for incoming sensory information and to prepare the sensory system for coming movements. An incomplete inner model of the internal representation will, according to Hirschfeld (1991), result in incomplete and blurry predictions of what actions will follow the sensory inputs and thereby anticipatory actions will be ineffective and affect the movement negatively.

Before treatment all participants were unable to continue walking and at the same time answer a simple question such as what they had done the day before, or to observe and account for what was happening parallel to the sidewalk. To be able to observe anything in the surroundings they all immediately stopped and turned the whole body as a "block". When asked a question, they all stopped before answering (Lundin-Olsson et al., 1997). Therefore it was vital to include exercises in the training programme with the focus on perceptual and cognitive skills as well as including co-ordinated arm movements and spinal rotation to improve balance and postural control.

The prosthesis itself was regarded as something unreliable, causing pain and discomfort before treatment, which was also found by Hagberg and Brånemark (2001). Just like persons in studies with prosthetic users due to thalidomide, a major part of the participants stated that the prosthesis was used mainly for cosmetic reasons, and that they thereby looked less deviating (Paulsson, 1995). In the present study the participants also stated that the prosthesis was not something you co-operated with. It was experienced as a foreign object and felt heavier and ungainlier than the intact leg. Thus the prosthesis became an object that reminded them of being handicapped and it was most evident when climbing stairs, uphill or downhill, walking in a crowd or in bad weather, e.g. in rain, snow or strong wind.

Basic training of motor functions was performed e.g. to alter gait speed, to turn round in both directions, to cope with different surfaces, terrain and weather, climbing and descending hills and stairs and crossing pavements. The goal of the training programme was to integrate the prosthesis in movements, to normalize and achieve freedom of movement including running and jumping, and to remove low-back pain. The individual training programme consisted of exercises selected and combined from several theories in physiotherapy ranging from basic to more advanced skills:

- activation of postural muscles to find the centre line and retain it while moving,
- exercises containing combination of steps, rotations and arm movements to improve strength, fitness, co-ordination and postural control,

- specially designed and selected movements to regulate exercise intensity, increase endurance and flexibility,
- training of perceptual and cognitive skills during movement.

Other important components were:

- always training out of doors in different environments and terrain,
- a therapeutic climate permitting both positive and negative emotional expressions,
- the use of a conscious therapeutic approach.

A conscious therapeutic approach and creating a therapeutic alliance (paper I)

The initial interview (paper V) aimed at obtaining knowledge about the participant's personal history, which is helpful for the therapist (Antonovsky, 1991). It is by this first interview that one may understand the representation of the loss (Antonovsky, 1991). This interview also aimed at making the participant attach to the therapist, thereby creating a relationship, which served as a starting-point for a working alliance (Luborsky, 1984).

During treatment deliberate actions were made to keep a good working climate of sympathetic understanding and trust (Luborsky, 1984). This is achieved by techniques normally used in psychiatric therapy, e.g. meeting the patient with empathy and respect, giving warm mental support, using precise framework and keeping regular contact (Sivik, 1990). The therapist is supposed to maintain a neutral and professional attitude, acting only as a mirror, reflecting what is obvious, leaving interpretation to the patient (Everstine and Everstine, 1986). When a significant change occurs, this attitude brings about a feeling of independence for the participant, being capable of making progress on his/her own. Too generous and too frequent praise on the other hand can make the participant insecure in terms of his/her own ability (Everstine and Everstine, 1986). Using a conscious therapeutic approach meant, among other things, staying neutral, not making therapeutic predictions or other promises that could not be kept (Flegenheimer, 1992). It also implied refraining from trying to soothe the patient's anxiety or trying to cheer the patient up. Trying to persuade a patient to "look at things from the bright side" negates the sense of reality and implies that the patient's problems are small and nothing to worry about (Everstine and Everstine, 1986).

Staying neutral also meant acting as a mirror to what was being said and what was being performed (Everstine and Everstine, 1986; Flegenheimer, 1992). If, for example, a participant claimed to have been practising all week and the therapist noticed that there was no improvement that could match such an effort, the therapist would say, "I hear what you say, but my eyes tell me something else." This statement has no judgement or value but gives room for interpretation by the participant, either he/she has not trained or has trained in the wrong way. It may explain to the participant that good results depend not only on the therapist or the participant, but are mutual achievements based on trust and understanding.

During training all feelings were allowed to be shown and were mirrored by the therapist. These feelings could be happiness and joy, but they could also contain fear of failing, anger and frustration directed toward the prosthesis or the therapist. When feelings were positive all credit and praise belonged to the participant. Negative ones were handled by the physiotherapist while remaining neutral and acting again as a mirror, saying, "I notice that you are upset, can you tell me what you are feeling or what you are thinking?"

The training procedure (paper I)

Treatment was regularly scheduled at weekly intervals, always the same time and day of the week, for about one and a half hours. Every treatment session started with the therapist asking what had happened during the week. The answer served as a guide to the therapist to choose the intensity and degree of difficulty of the first exercise. If the participant had had a really poor week, the treatment would start with exercises that the participant especially enjoyed or performed really well, this in order to raise self-confidence and acquire full focus on the training and perception of the movement. All treatment sessions were conducted by one physical therapist (CS), especially trained and experienced in psychiatric and orthopaedic care. The treatment period averaged 10 months (range 7–14). In two cases treatment was interrupted for five and six weeks respectively, waiting for parts required to repair the prosthesis.

Every session was evaluated by the therapist and the participant together. The credit of accomplishment belonged solely to the participant. No specific homework was assigned or suggested. The treatment continued until the participant performed the complicated sequenced tasks without hesitating or stopping.

The training environment (paper I)

All training took place out of doors, the aim being to create a flexible and normalized gait technique (Bergland, 1994; Shumway-Cook and Woollacott, 1995).

The participants started by walking in sand, a material chosen for its special qualities. Walking with an imbalance causes the sand to give way and the participant to lose balance. However, when the walking technique was correct and the participant put weight on the prosthesis, there was almost no problem in keeping the balance. By just instructing the participant to turn around and watch the footprints in the wet sand, they could observe that there was an obvious difference. The intact leg left deep and obvious marks, whereas the prosthetic leg barely was visible on the sand. Thereby a lot of time was saved in motivating and instructing the participant and it also served as a powerful feedback.

Before treatment all participants were dependent on looking down, paying attention to the ground to reveal possible obstacles or irregularities, which in turn meant that the body was bent forward. This posture caused the knee on the prosthesis to become unstable as the flexed pattern made it more difficult to have a proper heel-strike and this created a vicious circle. Feelings of insecurity were increased, thereby resulting in an increased forward position of the body. Another consequence of looking down on the ground is that the vestibular system is given poorer conditions to function, which in itself further affects balance capacity in a negative way (Shumway-Cook and Woollacott, 1995). According to these authors somatosensory information normally has higher priority than vestibular and visual information. A typical pattern of patients with inflexible use of somatosensory inputs for postural control is that they get unsteady and lose their balance when the surface, for example, is compliant, like sand, and surface inputs do not help the subject to establish and maintain an upright position. This pattern is referred to as a surface-dependent pattern. Visual information has its main function for maintaining a vertical orientation and postural control by making use of information at a long range (Shumway-Cook and Woollacott, 1995). In this group of amputees visual information seemed to replace information from the somatosensory system.

In this phase the exercises included observing the surroundings by looking in different directions, except down at the surface. The training aimed at improving the proprioception and the interpretation of the information from the remaining somatosensory receptors, thereby increasing the sensitivity of feeling the position of the prosthetic foot. The participants also had to distribute the body weight on both legs, and special emphasis was put on the hip extension at push off. This part of the training was necessary to integrate the prosthesis and to involve the amputated side of the body to create a whole.

Walking in sand at the beginning of training had another advantage. It was very strenuous and heavy for the participants to walk in. However, when the training continued on firmer surfaces the participants felt as if they were almost weightless. The heavy resistance from the sand was gone, and the improved technique helped to keep an erect posture. The training then proceeded to take advantage of all sorts of surfaces and terrain provided in the forest, on the beach or in the park and other similar environments. Obstacles were created by using branches from trees, walking in wet leaves and changing from asphalt to high grass and so on. This was done in order to improve proprioception and to obtain a flexible gait technique. The weather was also a challenge as most of the participants reported before training that they avoided going outside as much as possible if there was snow or strong wind. Training therefore took place in all sorts of weather.

Gait speed (paper I)

Gait speed was measured by VICON 370 (version 1.2, Oxford Metrics Ltd, Oxford, UK). This is a three-dimensional motion analysis system consisting of five 50 Hz cameras with infrared strobes, and one data station (Pentium II, 350 MHz processor) and one PC where the information was gathered and processed in VICON Clinical Manager (VCM, 1995). Ground reaction forces were collected using one Kistler force-plate (a piezoelectric transducer, type 9284). Gait speed was calculated as the mean speed of the first three trials at self-selected comfortable and brisk speeds, respectively. The mean speed was chosen as no signs of intra-variations in gait speed were found before or after treatment or at follow-up after six months.

Gait analysis (papers II and III)

Gait analysis was performed by VICON 370 (version 1.2, Oxford Metrics Ltd, Oxford, UK). Special lightweight surface markers were attached directly to the skin or the prosthesis and placed over standardized landmarks or corresponding spots on the prosthesis according to the biomechanical model of Kadaba et al. (1990) and Davis et al. (1991). On the prosthesis the knee marker was placed over the joint centre and the ankle marker was attached to the spot corresponding to the lateral malleolus on the intact side. Two additional markers were placed between the scapulae, one at the height of the scapular spines and the other at the height of the inferior angles to include upper-body movements. Their position enabled a visual assessment of movements of the trunk in the frontal plane. Calculation methods and model assumptions have been described in detail by Kadaba et al. (1990) and Davis et al. (1991).

The subjects wore their own normal walking shoes when measured before and after treatment and at follow-up. The same shoes were used on all three occasions.

The gait path was 12 m long with a force-plate built in at floor level and covered with a thin rubber carpet to avoid visual aiming for the force-plate during gait tests. The participants were asked to walk at self-selected comfortable gait speed. Recordings of five accurate strikes on the force-plate of the intact and the amputated leg respectively were made. When processed, all five trials were presented as graphs in one figure. The most representative graph out of the five (i.e. the median) was chosen and the mean value from the nine subjects was used in the calculations and figures. As the laboratory has one force-plate, values for the amputated and intact side in the tables represent median values assessed at different trials and therefore some of the spread in the ranges may have been caused by slight variations of gait speed. Due to a technical problem the data from before treatment are missing in one participant.

All documented values are peak values of different phases in the gait cycles and values for moment were normalized to body mass. Internal moments were calculated and interpreted as muscles and ligaments counteracting the external moments produced by ground reaction force (Gage, 1991). The product of joint net moment and joint angular velocity, the net muscle power, was calculated, with positive values representing generating power, i.e. concentric muscle activity, and negative values representing absorbing power, i.e. eccentric muscle activity (Gage, 1991).

The reference group was measured with the same procedure for the left and right leg. As no significant difference was found between the left and right leg, mean values for both legs were used in the calculations.

In all the figures, 100 percent of the x-axis is equivalent of one stride, starting with heel-strike at 0 percent. All figures represent movements or moments of either the amputated or the intact side. Kinematic and kinetic data are interpreted in the conventional way of clinical gait analysis in comparison to a reference group and also in conjunction with a clinical and visual evaluation as described by Gage (1991) and Stout (1995), aiming to define primary impairments and secondary compensatory mechanisms.

Oxygen consumption, heart rate, respiratory quotient, energy cost and lactate concentration (paper IV)

Gait speed data, measured with VICON 370 (version 1.2, Oxford Metrics Ltd, Oxford, UK), was collected 3–5 days before the energy-consumption measurement and the preset speed on the treadmill was calculated from these data.

On the day of the metabolic test all participants were instructed to eat a normal breakfast and not to eat or drink anything afterwards, except water. All the tests started approximately four hours after breakfast. The weight of each participant with prosthesis was measured on a standard physician's beam scale. The height was measured to the nearest 0.5 cm on a standardized wall-mounted height board.

A maximum walk test was performed on a treadmill (Marquette Treadmill 1900, Marquette Electronics, Milwaukee, WI, USA) with infinitely variable speed (maximum speed 6 $m \times s^{-1}$). Expired gas was sampled continuously via a mixing chamber and analysed for the concentration of O_2 and CO_2 in a pulmonary gas exchange system (Sensor Medics 2900, Sensor Medics CO, Yorba Linda, CA, USA). A mouth-breathing face mask was used, with a nose chamber isolating the nose from the breathing pattern (Hans Rudolph, Inc., Kansas City, USA). Measurements were obtained every 20 s during the whole session. Maximum oxygen consumption was determined as the highest value recorded during the last minute of exercise. All oxygen consumption measurements were carried out by one laboratory assistant at the Department of Clinical Physiology, University Hospital of Malmö, assisted by one physiotherapist (CS).

The participants were allowed to test the treadmill for about 5–10 minutes to get used to it. During this test it was found that the self-selected comfortable and brisk speeds that had been established during the gait analysis measurements had to be reduced by 0.14 $m \times s^{-1}$ in all participants, for them to be able to walk continuously on the treadmill. The maximum gait speed was also established on this occasion. After testing the treadmill, the participants sat down for 15 minutes. ECG (electrocardiogram) electrodes and a face mask were applied and the participant rested for an additional two minutes, while heart rate and oxygen consumption were registered. During the treadmill test the participants wore a safety girdle, which was attached to the ceiling.

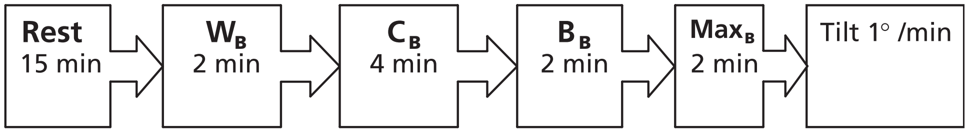
The walk test on the treadmill started with a warm-up consisting of two minutes walking with the participants' preset comfortable walking speed reduced by 0.25 $m \times s^{-1}$. It proceeded with the preset and reduced comfortable walking speed for four minutes, with the preset reduced brisk speed for two minutes and their self-selected maximum walking speed for two minutes (Fig. 2). Thereafter, the treadmill was tilted upwards by one degree/min until the participants no longer were able to continue at their maximum speed. The treadmill had railings on both sides but the participants were only allowed to hold lightly on the railings to feel secure. The three participants using walking aids before treatment were allowed to take support, but not to lean, on the side where they usually used a stick.

The participants reported the degree of perceived exertion on Borg's scale (Åstrand et al., 2003) every second minute until the end of brisk walking speed and once immediately after the test was finished. They were urged to continue to maximal exhaustion (17–19 on Borg's scale). When they had finished walking they were allowed to sit down, but continued to breathe in the mask for another four minutes. The participants' comments were assessed at the end of the measurements.

Capillary blood samples (10 µl) were obtained from a fingertip for measurement of blood lactate concentration (Lange 8, LPG 258, Mini photometer, Germany). The blood was sampled after finishing every period of brisk speed, maximum speed, immediately after interrupting the measurements, and after two and four minutes during the recovery phase.

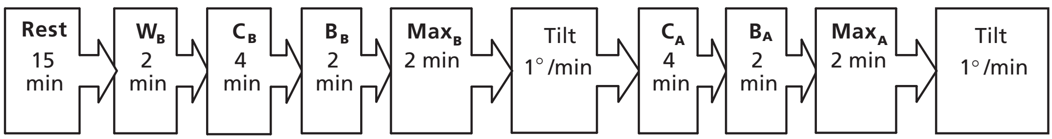
The tests after treatment and at follow-up six months later had the same design, but now the new gait speeds were added to the protocol (Fig. 2). First the participants repeated the tests in the preset speeds chosen before treatment. The participants then continued to walk without any resting period following the protocol one more time, but now walking with the new improved gait speeds (Fig. 2). At follow-up, the participants were measured following the same procedure as in the test after treatment.

M1



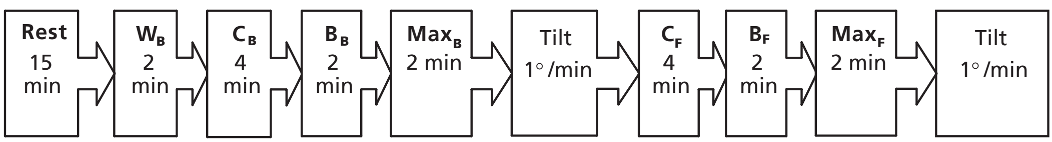
M1 = Measurement before treatment: (W_B = warm-up speed chosen before treatment; C_B = comfortable speed chosen before treatment; B_B = brisk speed chosen before treatment; Max_B = maximum speed chosen before treatment).

M2



M2 = Measurement after treatment: (W_B = warm-up speed chosen before treatment; C_B = comfortable speed chosen before treatment; B_B = brisk speed chosen before treatment; Max_B = maximum speed chosen before treatment; C_A = comfortable speed chosen after treatment; B_A = brisk speed chosen after treatment; Max_A = maximum speed chosen after treatment).

M3



M3 = Measurement at follow-up: (W_B = warm-up speed chosen before treatment; C_B = comfortable speed chosen before treatment; B_B = brisk speed chosen before treatment; Max_B = maximum speed chosen before treatment; C_F = comfortable speed chosen after treatment and at follow up; B_F = brisk speed chosen at follow up; Max_F = maximum speed chosen at follow up).

Fig. 2. The design of comparing of oxygen consumption before and after treatment and at follow-up, when the participants were walking with the same speed as chosen before treatment at all three occasions, and secondly when they were walking with their improved self-selected comfortable, brisk and maximum speed after treatment and at follow-up.

Interviews (paper V)

Procedure

Data were collected using a semi-structured interview. The informants were interviewed before the intervention by one physiotherapist (CS) for 60 to 90 minutes and all interviews were recorded on tape. All gave their written consent. Only open questions were used related to the research questions and special areas of interest. The interview guide consisted of: (1) experiences in immediate relation to the amputation including the time spent at the ward, (2) experiences after discharge, (3) self-image and body image. Follow-up questions were asked to clarify the verbal meanings and/or the emotions. In five cases the first interview exceeded 90 minutes and a second interview was conducted within a week.

Data analysis

The raw data were transcribed verbatim for each interview. The data were then processed as described by Merriam (1988) and Patton (1980), consisting of the following steps:

1. All the interviews were read separately several times in order to get an understanding of the essence of each interview.
2. The interviews were read to identify and categorize the primary patterns in the data.
3. Meaning units were formulated to try to catch the essence and meaning of the statements.
4. Clusters of different aspects emerged in the coded data and were organized in categories.
5. These clusters were referred back to the raw data, which was read through once again. The raw interviews were coded again and the coded sentences were cut out and placed in a "scrapbook" arranged by category (Merriam, 1988). This was done to validate the categories and make sure that no essential aspect had been left out.
6. The raw data as well as the significant statements extracted from these transcriptions were read and coded separately by three researchers. This was done to obtain consensus between the researchers, and to make sure that no further aspects appeared and that the coding of the data was correct.
7. The categories were described in two themes.

Each category is described and summarized in aspects and illustrated by quotations in italics. Every quotation is coded to assure that the original context can be quickly retrieved and that as great a coverage as possible of informants' experiences is achieved.

Statistics

For the gait analysis, Wilcoxon signed ranks test was used to calculate the training effect over time and Mann-Whitney U-test to analyse differences comparing the amputated to the intact side and these two to the reference group. A p-value <0.05 was regarded as significant. For the oxygen consumption study, Friedman's test was used to study differences over time and here a p-value <0.01 was regarded as significant.

Results

Gait speed (paper I)

After treatment, self-selected comfortable gait speed increased on average from 0.95 $m \times s^{-1}$ before to 1.40 $m \times s^{-1}$ and 1.39 $m \times s^{-1}$ after treatment and at follow-up, respectively. This improvement ranged from 20 to 79% (mean 50%) comparing before and after treatment. At follow-up the improvement remained at 52% compared to before treatment (Table 3). Self-selected brisk gait speed increased on average from 1.29 $m \times s^{-1}$ before to 1.65 $m \times s^{-1}$ after treatment and remained at that level at follow-up. Improvement of self-selected brisk gait speed was on average 31% and 32% after treatment and at follow-up respectively, compared to before treatment (Table 3). The standard deviation of each session, at both comfortable and brisk speeds, varied from 0.00 to 0.08 $m \times s^{-1}$.

Comments: Before gait re-education, gait speed in the group of transfemoral amputees was about the same as reported in several studies (Waters and Mulroy, 1999). Jaegers et al. (1995a) found gait speed to be 29% slower (mean 1.01 $m \times s^{-1}$) than the comfortable gait speed of non-amputees, and the variability in speed was low (Boonstra et al., 1993; Jaegers et al., 1995a). Gait speed after gait re-education was equivalent to normal speed according to Perry (1992). Eight subjects had increased their gait speed, matching their gender and age group, and one subject walked slightly slower than the results of Bohannon (1997).

Table 3. Self-selected comfortable and brisk walking speed ($m \times s^{-1}$) in transfemoral amputees before and after treatment and at six months' follow-up. Improvement is calculated in percent in brackets. SD = standard deviation.

	Comfortable speed ($m \times s^{-1}$)			Brisk speed ($m \times s^{-1}$)		
Case n:o	Before	After	Follow-up	Before	After	Follow-up
1	1.22	1.50 (22)	1.39 (14)	1.58	1.81(15)	1.75 (11)
2	0.78	1.17 (50)	1.11 (43)	1.00	1.47 (47)	1.53 (53)
3	0.69	1.14 (64)	1.19 (72)	0.89	1.36 (51)	1.33 (49)
4	0.69	1.19 (72)	1.28 (84)	1.11	1.50 (35)	1.47 (32)
5	1.08	1.50 (38)	1.53 (41)	1.44	1.83 (27)	1.81 (26)
6 [a]	1.31	1.78 (36)	1.56 (19)	1.58	2.06 (30)	1.81 (15)
7	1.39	1.67 (20)	1.56 (12)	1.81	1.97 (9)	2.06 (14)
8	0.69	1.19 (72)	1.39 (100)	0.97	1.44 (48)	1.61 (66)
9	0.67	1.45 (79)	1.50 (86)	1.19	1.39 (17)	1.44 (21)
Mean speed $m \times s^{-1}$	0.95	1.40	1.39	1.29	1.65	1.65
SD	0.30	0.24	0.17	0.33	0.27	0.23
Mean improvement %		50	52		31	32
SD		22	34		15	20

[a] Technical problems with the prosthesis at 6 months' follow-up.

Gait analysis by clinical observation (paper I)

The gait pattern in all participants after gait re-education was almost symmetric and body weight was equally distributed between the amputated and the intact side during standing and walking, assessed by observation and video recordings. None needed walking aids. In addition, seven participants learnt to jog using their ordinary prosthesis.

Self-reported differences after treatment (paper I)

After gait re-education, participants reported shopping for their clothes themselves for the first time since the amputation, going to outdoor concerts, attending festivals and dancing for the first time in years—and having fun doing it. Almost all low back pain had disappeared. The participants also reported a sense of increased freedom of choice in daily activities, increased self-confidence and improved quality of life.

Comments: Low-back pain has been shown to be significantly more common in transfemoral amputees (71%) than in the general population and was rated as even more bothersome than phantom limb pain or stump pain (Smith et al., 1999). We did not anticipate the long-lasting effect of the treatment on low-back pain and we did not realize that it would reduce pain to this extent. In a prospective study the effects on low-back pain should be measured more accurately.

Gait analysis (papers II and III)

Single support, cadence and step length

After treatment and at follow-up single support remained significantly shorter on the amputated side than on the intact side and in the reference group. There was a significant increase in gait speed and cadence, which remained significantly higher for the reference group than for the subjects. A significantly longer step length was found after treatment and at follow-up on both the amputated and the intact side compared to the reference group (Paper II, Table 3). The median step length with the amputated leg at self-selected comfortable gait speed was 0.73 m before treatment, 0.93 m after and 0.92 m at follow-up. The quotients of the step length between the intact and amputated leg increased from 0.86 before treatment to 0.88 after and 0.94 at follow-up (Paper III, Table 3).

Comments: The characteristic asymmetries in transfemoral amputee gait that we have reported have been shown in several studies (Inman et al., 1981; Boonstra et al., 1994). Stance phase is shorter and swing phase is longer on the prosthetic side (James and Öberg, 1973; Boonstra et al., 1994) and stance phase is increased with decreasing residual leg length (Jaegers et al., 1995). James and Öberg (1973) studied 34 healthy transfemoral amputees and found that this asymmetry was unaffected by increased speed. The majority of the patients took a longer step with the prosthetic leg, even at fast speed. The amputated person produced higher gait speed with increased stride length rather than increased cadence (steps/min) (James and Öberg, 1973). Boonstra et al. (1993) found that the amputated person could only vary gait speed with the healthy leg, because of the inability of the artificial knee joint to adjust actively.

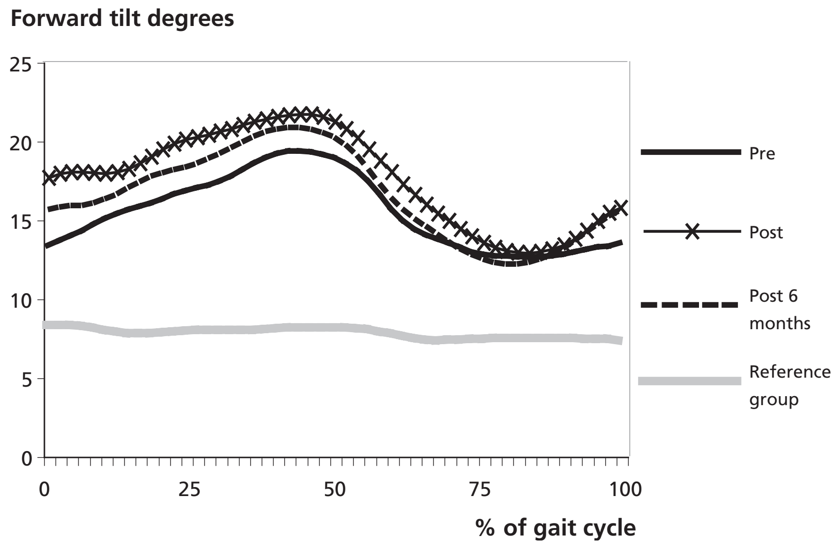


Fig. 3. Mean values of pelvic tilt (degrees) in the sagittal plane of the amputated side at self-selected comfortable speed (N=9).

Despite the fact that the participants in the present study still took longer steps with both legs than the reference group to increase gait speed, there was no significant difference in step length between the legs. Cadence increased significantly, but was still less than in the reference group. Jaegers et al. (1995) made the same finding when studying prosthetic gait in transfemoral amputees and interpreted it as a typical sign of pathological gait as opposed to normal gait, where cadence increases with increased gait speed. In our study, single and double support did not change after treatment on the amputated side, but the values showed less variability than before treatment in both legs. This indicated a more stable and symmetrical pattern, although the single and double support values may have been slightly high before treatment as three participants were dependent on walking aids before treatment. Also, an error in the measurements may have been introduced, as some parts of the processing, for example marking heel-strike and toe-off, are done manually, and they occur within one hundredth of a second.

Kinematic and kinetic data in the sagittal plane (paper II)

All the nine amputees had stable walking patterns and there was almost no sign of intra-variations.

Pelvis

The shape of the movement graph of the pelvis was unchanged after treatment and at follow-up on both sides. During stance-phase, the pelvis was tilted forward on the amputated side and during pre-swing it was tilted backwards. The tilting of the pelvis was more than twice as large as in the reference group, where it was stable at 8 degrees (Fig. 3).

Table 4. Median peak values and ranges of movement, moment and power in the sagittal plane in hip, knee and ankle related to the gait cycle in transfemoral amputees before and after treatment and at follow-up. Corresponding values for the reference group are also shown.

	Amputated side			Intact side			Ref group
	Before	After	Follow-up	Before	After	Follow-up	
Hip flexion (degrees)	31	38 [a]	37 [c]	49	57 [a]	52	34
range	21–47	25–55	25–52	42–56	44–68	39–66	26–54
% of gait cycle	2	0	0	4	4	4	2
Concentric power in hip extensors (w/kg)	0.8	1.5 [a]	1.3 [c]	1.2	1.6	1.6	1.0
range	0.0–1.5	0.1–4.6	0.4–3.4	0.1–2.2	0.2–3.4	1.2–2.2	0.1–3.3
% of gait cycle	8	6	8	10	12	12	14
Eccentric power in hip flexors (w/kg)	0.6	0.9 [a]	0.9	0.5	0.7	0.8	0.8
range	0.1–1.2	0.4-2.5	0.6–1.8	0.1–1.01	0.2–2.1	0.2–1.4	0.2–1.7
% of gait cycle	44	44	46	50	44	50	42
Hip flexion moment (Nm/kg)	0.9	1.0 [a]	1.0	0.9	1.2 [a]	1.1	1.0
range	0.3–1.1	0.7–1.8	0.5–1.6	0.3–2.0	0.7–1.4	0.1–1.6	0.4–1.4
% of gait cycle	50	48	50	50	56	54	52
Knee flexion (degrees)	0	0	0	33	39	36	22
range				20–35	23–41	16–47	10–31
% of gait cycle	14	16	14	16	14	14	14
Knee extension moment (Nm/kg)	-0.3	-0.2	-0.2	0.6	1.0	1.0	0.4
range	-0.5–0.4	-0.6–0.3	-0.6–0.0	0.5–0.9	0.4–1.4	-0.1–0.3	0.0–0.7
% of gait cycle	22	18	16	14	14	14	14
Eccentric power q-ceps (w/kg)	0.0	0.0	0.0	-0.6	-1.8 [a]	-1.7 [b]	0.4
range	0.0–0.0	-0.1–0.0	0.0–0.1	0.3–0.9	0.3–3.0	0.3–3.2	-1.0–0.0
% of gait cycle	10	10	10	10	10	10	10
Concentric power in q-ceps (w/kg)	0.0	0.0	0.0	0.5	1.2 [a]	1.0 [c]	0.4
range	-0.1–0.2	0.0–0.2	-0.1–0.1	0.3–1.2	0.6–2.3	0.3–1.5	-0.1–1.0
% of gait cycle	20	20	20	20	20	20	20
Concentric power in ankle plantar flexors (w/kg)	0.2	0.5 [a]	0.5	1.7	2.9 [a]	2.9 [b]	2.1
range	0.0–0.7	0.3–0.8	0.2–0.8	0.6–2.1	1.2–3.5	1.2–3.4	0.5–3.8
% of gait cycle	52	50	52	56	56	56	54

P-values < 0.05 [a] before and after treatment, [b] before treatment and follow-up, [c] after treatment and follow-up (Wilcoxon signed ranks test).

Hip

On both sides hip flexion increased significantly after treatment. On the intact side the hip flexion was significantly larger than on the amputated side and in the reference group at follow-up (Tables 4 and 5). Generating power in the hip extensors almost doubled on the amputated side after treatment to about the same level as the intact side (Fig. 4). At follow-up the subjects showed no differences here between the legs but generating power in the intact leg increased compared to the reference group (Tables 4 and 5).

Table 5. Confidence levels for differences between the amputated and the intact side and each side to the reference group at follow-up (Mann-Whitney U test). (Conc=concentric, ecc=eccentric).

	Amputated/Intact side			Amputated side/ Reference group			Intact side/ Reference group		
Parameters	Pre	Post	Follow-up	Pre	Post	Follow-up	Pre	Post	Follow-up
Gait speed	0.959	0.730	0.605	<0.001	0.123	0.010	<0.001	0.035	0.016
Cadence	1.000	0.489	0.796	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Step length	0.161	0.258	0.297	0.622	<0.001	<0.001	0.169	0.005	0.013
Single support	0.279	<0.001	0.001	0.002	<0.001	<0.001	0.665	0.092	0.625
Double support	0.328	0.258	0.161	0.179	0.459	0.476	0.008	0.425	0.334
Hip									
Hip flexion	0.005	0.004	0.014	0.709	0.172	0.363	<0.001	<0.001	<0.001
Conc power in hip ext	0.195	1.000	0.258	0.360	0.146	0.459	0.520	0.071	0.009
Ecc power in hip flex	0.328	0.190	0.161	0.622	0.116	0.116	0.092	0.686	0.686
Hip flexion moment	0.442	0.546	1.000	0.075	0.665	0.706	0.011	0.123	0.748
Knee									
Knee flexion	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.006
Knee extension moment	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.006
Ecc power q-ceps	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.111	<0.001	<0.001
Conc power q-ceps	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.111	<0.001	<0.001
Ankle									
Conc power ankle plantar flexors	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.011	0.172	0.138

Hip flexion moment at pre-swing was almost symmetrical but was higher on the intact side after treatment and comparable to the reference group at follow-up (Tables 4 and 5). On the amputated side, the graph showed a much steeper curve from pre-swing to mid-swing than in the reference group, as if the prosthesis was being rapidly lifted (Fig. 5). This pattern was not altered after treatment.

Knee

On the amputated side the prosthetic knee was continuously extended during the whole stance-phase. On the intact side, during shock absorption, maximum knee flexion, moment and absorbing power increased after treatment and were significantly higher than in the reference group (Tables 4 and 5). Just after shock absorption, the generating power increased after treatment and remained at that level at follow-up, which was significantly higher than in the reference group (Fig. 6, Tables 4 and 5).

Ankle

Vaulting on the intact leg disappeared after treatment, but at follow-up there was a tendency for this pattern to re-appear (Fig. 7). Peak plantar flexion moment increased during treatment and remained at follow-up at the same level, which was higher than in the reference group (Fig. 7). Maximum generating power on the intact side increased after treatment and was not significantly different from the reference group at follow-up (Tables 4 and 5). There was a significant increase in generating power in the prosthetic foot after treatment, but not compared to the intact side and the reference group (Tables 4 and 5).

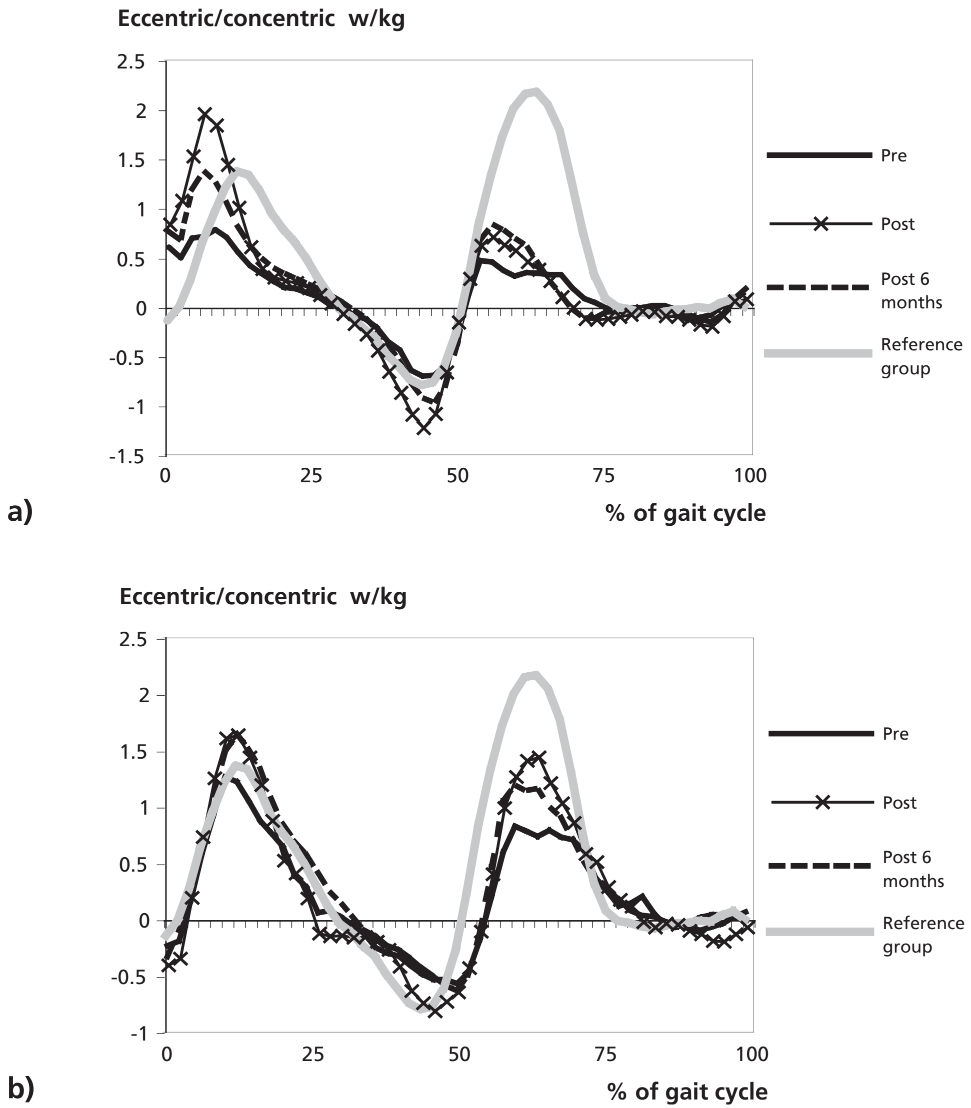


Fig. 4. Mean values of hip power (w/kg) in the sagittal plane of the amputated side (a) and the intact side (b) at self-selected comfortable speed (N=9).

Comments: Ability to carry and control the body weight during single support and hip extension at push-off was emphasized during training for both the amputated and the intact side. Therefore dynamic changes were especially expected in the sagittal plane. The forward/backward tilting of the pelvis may have been an effort to increase step length, which was significantly longer than in the reference group. The forward tilting of the pelvis during stance on the amputated side was probably also a way of controlling the ground reaction force to stabilize knee extension. There was an increased symmetry in generating power in the hips, which may have been an effect of the training. The important role of the hip extensors has

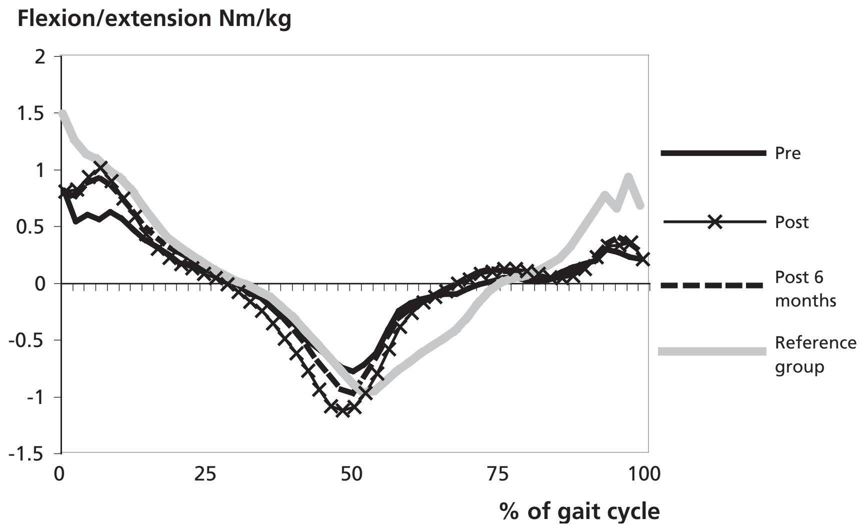


Fig. 5. Mean values of hip flexion/extension moment (Nm/kg) of the amputated side at self-selected comfortable speed (N=9).

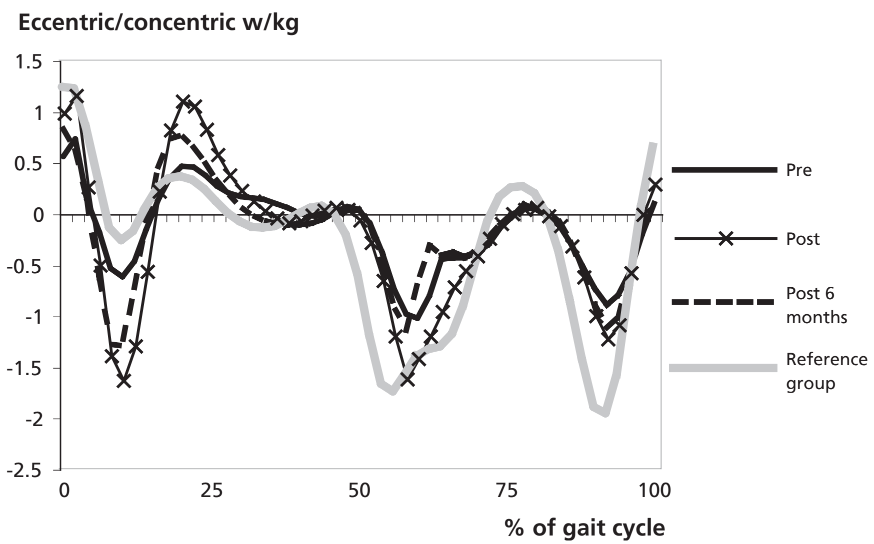


Fig 6. Mean values of knee power (w/kg) in the sagittal plane of the intact side at self-selected comfortable speed (N=9).

been emphasized during training of amputees in other models (Wahlborg-Kamwendo, 1979; Mensch, 1990; Mensch, 1993a; 1993b). Winter and Sienko (1988) found that a considerably increased concentric muscle activity in the hip extensors at the early heel-strike and at mid-stance probably was a compensation for the lack of plantar flexors, normally needed in late

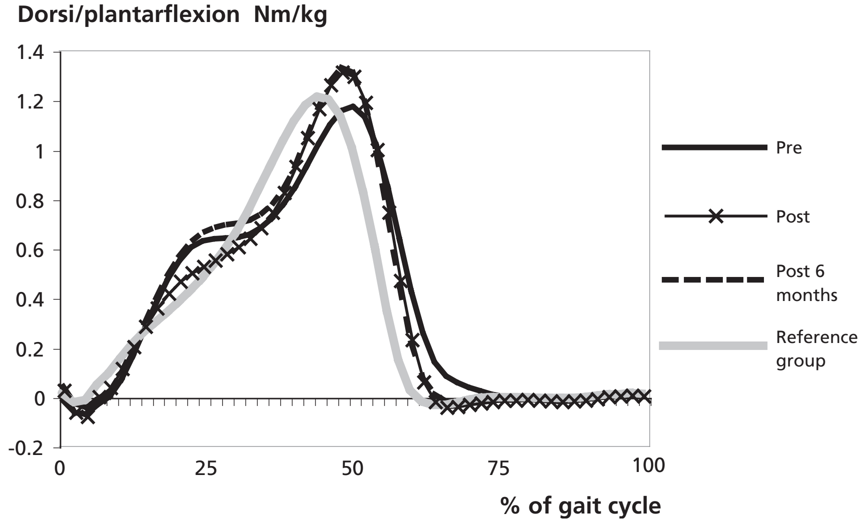


Fig 7. Mean values of ankle dorsi-/plantarflexion moment (Nm/kg) of the intact side at self-selected comfortable speed (N=9).

stance for propulsion. The amputated person also controls the prosthetic knee mainly using the decelerating power of the hip extensors (Hale, 1990). In our study, there was a considerable amount of increase in moments and absorbing and generating power in the intact knee during shock absorption and knee extension compared to the reference group. This increase may be an effect of the increased gait speed and a compensation for lack of shock absorption in the prosthetic knee. The significant increase in generating power in the prosthetic foot after treatment may be due to the participants putting body weight on the forefoot to be taking advantage of the energy-storing properties of the foot, which probably was an effect of the treatment.

Kinematic and kinetic data in the transverse and frontal plane (paper III)

Pelvic rotation in the transverse plane

On the amputated side there was an increased range of motion (ROM), where the pelvis was slightly more internally rotated during beginning of stance before and after treatment than in the reference group. The internal rotation increased further during this phase at follow-up compared to the intact side and the reference group (Fig. 8a, Tables 6 and 7). The shape of the movement graph seemed otherwise to be almost the same as the graph of reference group during the rest of stance phase, but was less externally rotated at the end of stance (Fig. 8a and Table 7). There was a tendency before treatment and at follow-up for the pelvis to rotate quickly towards an almost neutral position during the second period of double support. At the end of swing-phase the shape of the movement graph after treatment and at follow-up equalled the reference group (Fig. 8a, Tables 6 and 7).

As the pelvis functions as an entity, movements were reversed on the intact side. During the beginning of stance, it was therefore almost in a neutral position compared to the amputated side and the reference group before treatment and at follow-up. After treatment the shape of

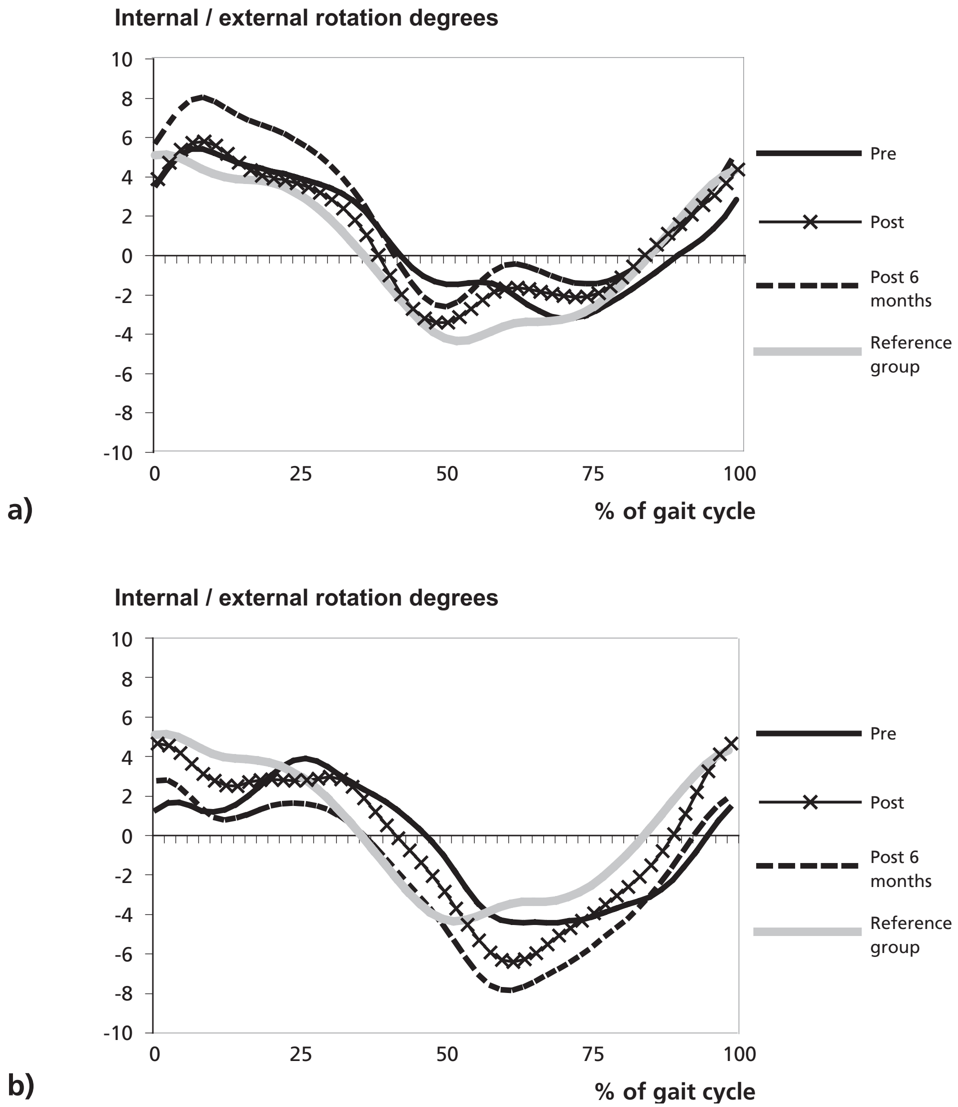


Fig. 8. Mean values of pelvic rotation in the transverse plane of the amputated side (a) and intact side (b) at self-selected comfortable speed before and after treatment and at follow-up (N=9). Positive values are degrees of internal rotation. Negative values are degrees of external rotation.

the graph equalled the amputated side and the reference group during this phase (Fig. 8b, Tables 6 and 7). The pelvis was more externally rotated on the intact side during the end of stance phase compared to the amputated side and the reference group after treatment, an effect which increased at follow-up (Fig. 8b and Table 7).

Table 6. Median peak values and ranges of movement (degrees) and moment (Nm/kg) in the transverse and frontal plane in pelvis, hip and knee related to the gait cycle in trans-femoral amputees (N=9) before and after treatment and at follow-up. Negative values in brackets. Corresponding values for the reference group (N=18) are also shown.

	Amputated side			Intact side			Ref group
	Before	After	Follow-up	Before	After	Follow-up	
Pelvis							
Pelvic rotation at							
8% of gait cycles	4	7	8	2	3	-1	4
range	0–14	(-1)–15	1–14	(-5)–6	(-10)–6	(-9)–7	(-2)–12
Pelvic rotation at							
100% of gait cycles	3	5	6	1	4	1	4
range	(-4)–10	(-3)–12	(-1)–8	(-3)–6	0–13	(-4)–8	(-3)–14
Pelvic obliquity	4	4	3	2	5 [a]	3 [b, c]	4
range	(-6)–9	(-4)–8	(-2)–7	(-2)–7	3–10	0–11	0–8
% gait cycles	14	12	12	8	8	8	14
Pelvic obliquity	-2	-5	-3	-4	-3	-2	-4
range	(-2)–7	(-9)–0	(-11)–(-1)	(-6)–4	(-8)–4	(-5)–1	(-7)–0
% gait cycles	52	52	52	66	66	66	66
Hip							
Abduction moment	0.5	0.5	0.4	0.5	0.6	0.4	0.7
range	0.2–0.7	0.1–0.7	0.1–0.7	0.1–0.9	0.1–1.1	0.1–0.9	0.2–1.1
% gait cycles	16	14	16	14	12	12	14
Abduction moment at							
30% of gait cycles	0.4	0.2 [a]	0.3	0.3	0.2 [a]	0.2 [b]	0.5
range	0.3–0.6	0.0–0.5	0.2–0.6	0.0–0.5	(-0.1)–0.4	0.0-0.3	0.2–0.7
Abduction moment	0.4	0.2	0.3	0.5	0.5	0.4	0.7
range	0.1–0.7	(-0.2)–0.7	0.1–0.8	0.2–0.7	0.1–0.8	0.1–0.7	0.3–1.1
% gait cycles							
Knee	42	42	40	16	14	14	14
Valgus moment	0.3	0.5	0.4	0.6	1.0 [a]	1.0	0.5
range	0.0–0.7	0.2–0.7	(-0.6)–0.0	0.1–0.4	0.1–0.7	0.1-0.7	0.1-0.7
% gait cycles	12	12	12	12	12	12	14
Valgus moment at							
30% of gait cycles	0.3	0.3	0.3	0.1	0.1	0.1	0.2
range	0.1–0.6	0.1–0.4	0.1–0.5	0.0–0.2	(-0.1)–0.2	(-0.1)–0.4	0.0–0.5
Valgus moment	0.3	0.3	0.3	0.2	0.4	0.3	0.4
range	0.0–0.5	0.0–0.4	0.1–0.6	0.1–0.6	0.2–0.6	0.0–0.7	0.1–0.6
% gait cycles	42	42	42	48	48	48	44

P-values < 0.05 [a] before and after treatment, [b] before treatment and follow-up, [c] after treatment and follow-up (Wilcoxon signed ranks test).

Pelvic obliquity in the frontal plane

On the amputated side, the pelvis was higher than in the reference group but slightly lower than the intact side during the beginning of stance, and this position remained unchanged after treatment and at follow-up (Fig. 9a, Tables 6 and 7). The pelvis then rapidly dropped about 8 degrees in the frontal plane during the rest of the stance phase. The shape of the curve was the same for the three measurements, but the pelvic drop increased after treatment and at follow-up. The range of movement was almost the same as that of the reference group, but the timing was different as the pelvis reached its lowest level by the beginning of single support, compared to during pre-swing in the reference group. During swing-phase the pelvis was lifted to a higher level than in the reference group (Fig. 9a and Table 6).

Table 7. Differences in pelvic, hip and knee parameters between the amputated and the intact side and each side compared to the reference group before and after treatment and at follow-up (Mann-Whitney U-test).

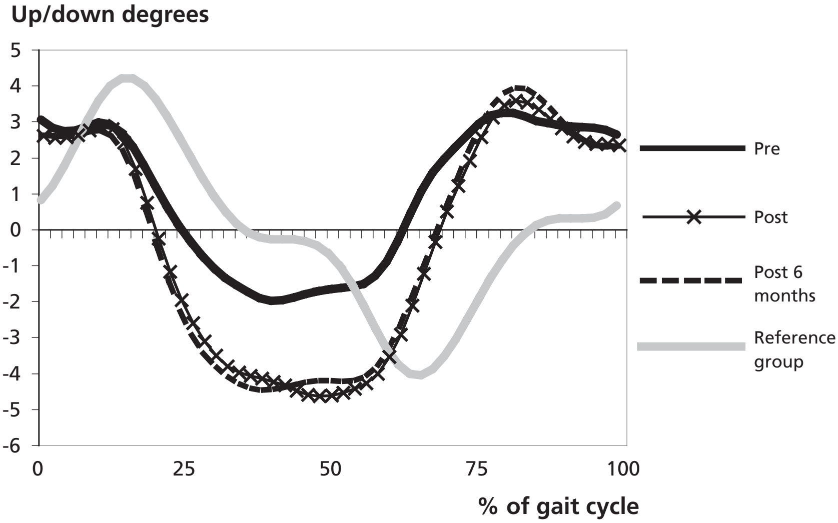
	Amputated/ Intact side			Amputated side/ Reference group			Intact side/ Reference group		
Parameters	Pre	Post	Follow-up	Pre	Post	Follow-up	Pre	Post	Follow-up
Pelvis									
Internal rot 8% of gait cycle	0.068	0.097	0.021	0.849	0.131	0.004	0.016	0.118	0.046
External rot 62% of gait cycle	0.446	0.038	0.021	0.285	0.011	0.017	0.849	0.027	0.001
Internal rot 100% of gait cycle	0.397	0.575	0.069	0.062	0.705	0.035	0.216	0.433	0.253
Obliquity 14% of gait cycle	0.624	0.091	0.012	0.177	0.212	0.131	0.080	0.253	<0.001
Obliquity 38% of gait cycle	0.399	0.229	0.854	0.013	0.860	0.820	0.935	0.031	0.176
Hip									
Abd moment 14% of gait cycle	0.734	0.171	0.888	0.022	0.006	0.007	0.160	0.433	0.046
Abd moment 30% of gait cycle	0.062	0.288	0.041	0.177	<0.001	0.004	0.002	<0.001	<0.001
Abd moment 44% of gait cycle	0.323	0.043	0.203	0.003	<0.001	0.002	0.047	0.046	0.003
Knee									
Valgus moment 14% of gait cycle	0.174	0.596	0.481	0.644	0.463	0.781	0.003	0.495	0.860
Valgus moment 30% of gait cycle	0.016	0.011	0.016	0.397	0.596	0.322	<0.001	<0.001	0.004
Valgus moment 44% of gait cycle	0.915	0.078	0.809	0.177	0.012	0.253	0.054	0.705	0.561

On the intact side, the position of the pelvis was higher at initial contact after treatment and at follow-up than on the amputated side and in the reference group (Fig. 9b, Tables 6 and 7). After loading response the pelvis dropped rapidly until mid-stance after treatment with significant differences compared to the reference group (Fig. 9b and Table 7). During swing-phase the pelvis was lifted to a higher level than the amputated side and the reference group after treatment and at follow-up (Fig. 9b).

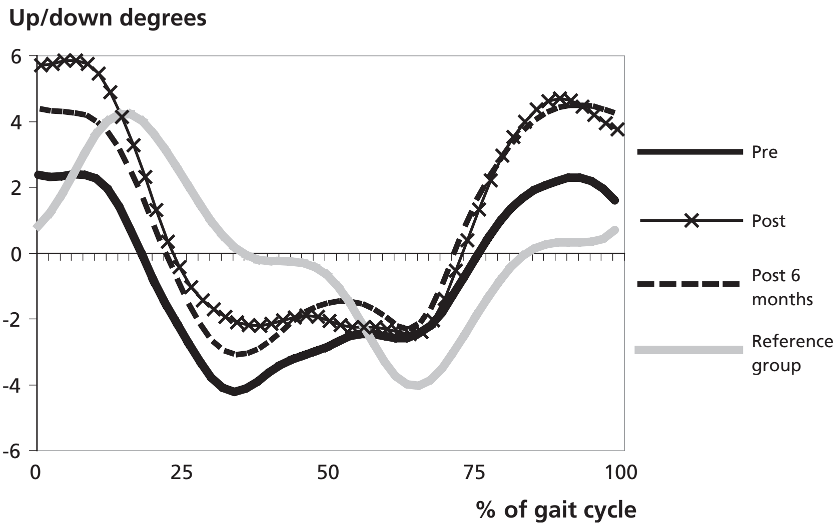
Both sides differed from the reference group, where the pelvis was held in a neutral position at initial contact and was moving upwards, about four degrees, to reach the peak value during loading response. The pelvis then slowly dropped and reached the peak value of about four degrees at the end of pre-swing. During the rest of the swing-phase position of the pelvis was back to neutral position (Fig. 9).

Hip abduction/adduction movement and moment

On the amputated side, the hip was held in an abducted position during stance phase, which increased after treatment and follow-up (Paper III, Fig 3). Hip abduction moment was about half of that of the reference group, and lacked the characteristic double maximum pattern. The



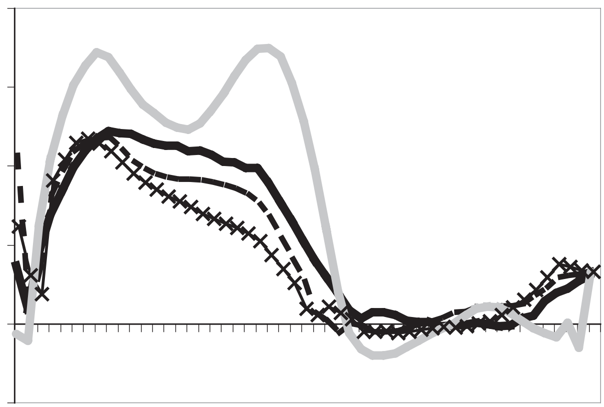
a)



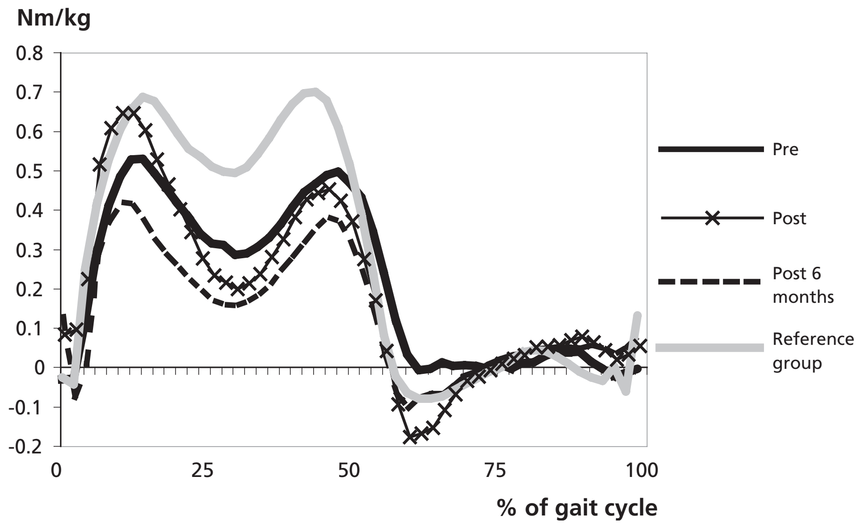
b)

Fig. 9. Mean values of pelvic obliquity in the frontal plane of the amputated side (a) and at the intact side (b) at self-selected comfortable speed before and after treatment and at follow-up (N=9). Positive values are degrees of upward oblique position of the pelvis. Negative values are the degrees of downward oblique position of the pelvis.

shape of the graph was slightly declining, especially after treatment (Fig. 10a, Tables 6 and 7). Compared to the reference group there were significant differences in all three measurements except during mid-stance before treatment (Table 7). There was a difference in timing, indicating a shorter stance phase on the amputated side than the intact side and the reference group (Fig. 10a and Table 6).



a)



b)

Fig. 10. Mean values of hip abduction moment of the amputated side (a) and the intact side (b) at self-selected comfortable speed before and after treatment and at follow-up (N=9).

On the intact side there was a tendency to adduct at the beginning of stance phase before and after treatment, although much less than in the reference group, and the hip was held in abduction during the rest of stance. The shape of the hip abduction moment graphs was the same as the reference group, but showed lower values, except at loading response after treatment, where almost the same value as the reference group was reached (Fig. 10b, Tables 6 and 7). There was a difference in timing, indicating a longer stance-phase than in the reference group (Fig. 10b and Table 6).

Knee valgus moment

On the amputated side, knee valgus moment was higher during the beginning of stance phase than on the intact side and in the reference group after treatment and at follow-up. The characteristic double maximum pattern was lacking and the shape of the graph was smoothed out (Table 6; Paper III, Fig. 5a). There were significant differences between the amputated and intact sides at mid-stance before, after treatment and at follow-up (Table 7). Peak values during push-off were lower than on the intact side and the reference group after treatment (Table 7; Paper III, Fig. 5a) and increased to the same level as the intact side at follow-up (Paper III, Fig. 5a and 5b). There was a difference in timing, indicating a shorter stance phase on the amputated side than in the intact side and in the reference group (Paper III, Fig. 5a and 5b).

On the intact side, there was the same characteristic double maximum pattern as in the reference group, but there was a difference in timing, indicating a longer stance-phase than in the reference group (Paper III, Fig. 5b). Peak values during loading response and push-off increased after treatment and at follow-up, but did not reach the same level as the reference group (Table 6; Paper III, Fig. 5b). During mid-stance values rapidly decreased to their lowest level at 30% of the gait cycle, which was much lower than in the amputated side and in the reference group (Tables 6 and 7; Paper III, Fig. 5b).

Comments: There was an increase in pelvic external rotation on the intact side at the end of stance phase after treatment, which increased further at follow-up, and consequently the pelvis was proportionally more internally rotated at the beginning of stance on the amputated side. These movements were probably an effect of the training and helped to increase step length. We have only found one article reporting kinematic and kinetic three-dimensional gait analysis of transfemoral amputees in the transverse and frontal plane. Tazawa (1997) also found that in good walkers, the pelvis of the prosthetic side never moved behind the pelvis of the intact side during an entire gait cycle. In the frontal plane, the increase in pelvic obliquity on the amputated side may be a result of movements in the soft tissue, i.e. piston action. A part of the oblique movement may also be due to weakness in the abductors causing Trendelenburg gait. Both hips were held in abduction, which increased after treatment and indicated that stride width was increased. The reduction in moment in both these graphs during mid-stance and terminal stance after treatment and follow-up, may have been caused by increased stride width and lateral trunk bending over the stance leg in order to reduce the lever arm to compensate for dysfunctional abductors (Berger, 1992; Jaegers et al., 1995a). Some of these results may also have been due to difficulties in stabilizing the socket medio-laterally (Berger, 1992).

The increased stride width was probably used to support balance, and it may have increased further with the increased gait speed, an effect also found by James and Öberg (1973). Another explanation may be that increased stride width was an attempt to reduce pressures inside the socket (Berger, 1992). Also, the socket position does not fully reflect the position of the femur and therefore another explanation for the shape of the curves in the abduction moment graph may be tissue movements inside the socket. Such motion has been measured during stance and swing by plain X-ray (Lilja et al., 1993), ultrasound transducers (Convery and Murray, 2000) and Roentgen stereophotogrammetry (Soderberg et al., 2003) and is several centimetres in multiple directions between the socket and skeleton.

Table 8. Oxygen consumption (O_2 ml × min^{-1} × kg^{-1}), heart rate, respiratory quotient (RQ) and energy cost of walking (O_2 ml × kg^{-1} × m^{-1}) in six transfemoral amputees before and after gait re-education and at six months' follow–up. Comfortable, brisk and maximum speed was chosen before treatment. Median values with ranges in brackets.

	Pre	Post	Post 6 months
Comfortable speed, 0.79 m × s^{-1}			
O_2 ml × min^{-1} × kg^{-1}	12.2 (10.6–17.9)	12.2 (9.7–15.7)	12.8 (9.8–14.4)
Heart rate	122 (95–138)	115 (92–131)	110 (100–119)
RQ	0.84 (0.80–0.90)	0.76 (0.65–0.85)	0.78 (0.74–0.88)
O_2 ml × kg^{-1} × m^{-1}	0.27 (0.20–0.35)	0.26 (0.21–0.31)	0.22 (0.20–0.30)
Brisk speed, 1.14 m × s^{-1}			
O_2 ml × min^{-1} × kg^{-1}	13.7 (12.1–20.2)	13.7 (11.2–20.2)	15.2 (11.3–16.4)
Heart rate	134 (109–152)	127 (100–152)	119 (109–146)
RQ	0.88 (0.82–0.93)	0.81 (0.77–0.89)	0.83 (0.80–0.89)
O_2 ml × kg^{-1} × m^{-1}	0.21 (0.16–0.27)	0.20 (0.19–0.25)	0.20 (0.15–0.26)
Maximum speed, 1.32 m × s^{-1}			
O_2 ml × min^{-1} × kg^{-1}	17.3 (12.7–22.8)	17.9 (12.5–24.0)	15.1 (11.6–22.8)
Heart rate	153 (110–164)	140 (110–173)	137 (111–169)
RQ	0.97 (0.94–1.03)	0.88 (0.83–0.96)	0.92 (0.82–0.99)
O_2 ml × kg^{-1} × m^{-1}	0.21 (0.18–0.27)	0.23 (0.19–0.24)	0.21 (0.18–0.22)

Oxygen consumption, heart rate, respiratory quotient, energy cost and lactate concentration (paper IV)

Oxygen consumption at the three gait speeds chosen before treatment did not change after treatment and at follow-up. Although not significantly, there was a tendency for heart rate, respiratory quotient (RQ) and energy cost of walking to decrease after treatment and at follow-up (Table 8).

In all three increased self-selected speeds after gait re-education, oxygen consumption and heart rate increased after treatment and remained so at follow-up (Table 9). Although not significantly, RQ also had a tendency to increase after treatment (Table 9). Energy cost of walking at self-selected comfortable speed after treatment had a tendency to decrease and remained at this level at follow-up (Table 9).

There was a decrease in the capillary blood lactate concentration after treatment and at follow-up when walking at the same maximum gait speed as chosen before treatment (Fig. 11). There was a tendency for the lactate level to decrease at the other speeds too.

All participants stated maximal exhaustion (17–19 on Borg's scale) at the end of the test. Almost all the participants commented after finishing the measurements that the maximum gait speed was limited by restrictions in the prosthetic knee joint, and three reported fear that the prosthesis would slide off due to perspiration.

Comments: The improved self-selected speeds chosen by the participants after training indicated improved walking skills. This was supported by a tendency to decrease in the energy cost of walking at the improved comfortable speed chosen after training. There was a significant increase in maximal oxygen uptake and maximal recorded heart rate, indicating that there was no true increase on the maximal aerobic capacity of the participants after training. Walking with the new, swifter, self-selected speeds after training was due to improved ability of the participants to use their inherent metabolic resources. Heart rate, respiratory quotient and

Table 9. Oxygen consumption (O_2 ml × min^{-1}× kg^{-1}), heart rate, respiratory quotient (RQ) and energy cost of walking (O_2 ml × kg^{-1} × m^{-1}) in six transfemoral amputees at self-selected comfortable, brisk and maximum speed chosen before and after gait re-education and at six months' follow-up. Median values with ranges in brackets.

	Self-selected gait speed chosen before and after treatment and at follow-up			
	Pre	Post	Post 6 months	Friedman's test
Comfortable speed				
Gait speed m × s^{-1}	0.79 (0.56–1.25)	1.21 (1.00–1.53)	1.20 (0.97–1.42)	p<0.01
O_2 ml × min^{-1} × kg^{-1}	12.2 (10.6–17.9)	16.6 (12.4–21.7)	16.0 (13.3–20.1)	p<0.01
Heart rate	122 (95–138)	141 (118–175)	137 (120–165)	p<0.01
RQ	0.84 (0.80–0.90)	0.87 (0.85–0.93)	0.91 (0.83–0.94)	NS
O_2 ml × kg^{-1} × m^{-1}	0.27 (0.20–0.35)	0.23 (0.21–0.24)	0.23 (0.20–0.24)	NS
Brisk speed				
Gait speed m × s–1	1.14 (0.75–1.67)	1.52 (1.22–1.83)	1.50 (1.19–1.92)	p<0.01
O_2 ml × min^{-1} × kg^{-1}	13.7 (12.1–20.2)	19.3 (15.9–26.1)	19.3 (14.2–24.1)	p<0.01
Heart rate	134 (109–152)	161 (145–182)	155 (136–171)	p<0.01
RQ	0.88 (0.82–0.93)	0.91 (0.84–0.99)	0.96 (0.85–1.01)	NS
O_2 ml × kg^{-1} × m^{-1}	0.22 (0.20–0.27)	0.24 (0.22–0.28)	0.23 (0.20–0.26)	NS
Maximum speed				
Gait speed m × s^{-1}	1.32 (0.89–1.81)	1.58 (1.22–1.89)	1.52 (1.25–1.92)	p<0.01
O_2 ml × min^{-1} × kg^{-1}	17.3 (12.7–22.8)	20.8 (17.3–28.2)	20.1 (15.8–29.0)	p<0.01
Heart rate	153 (110–164)	168 (154–198)	163 (154–177)	p<0.01
RQ	0.97 (0.94–1.03)	0.98 (0.91–1.00)	0.97 (0.89–1.04)	NS
O_2 ml × kg^{-1} × m^{-1}	0.21 (0.18–0.27)	0.23 (0.20–0.28)	0.24 (0.20–0.26)	NS

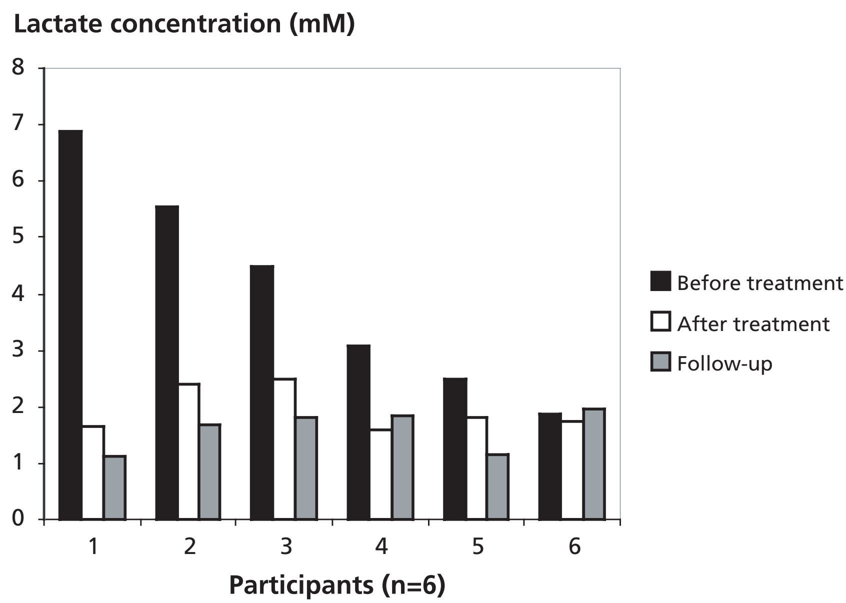


Fig. 11. Comparison of capillary blood lactate concentration (mM · l^{-1}) in transfemoral amputees before and after gait re-education and at follow-up, during walking at the same maximum speed chosen before treatment (n=6).

oxygen consumption remained at the same level after training when walking with the same speed as chosen before treatment. This was also an indication that there was no improvement in physical fitness.

Coping after transfemoral amputation (paper V)

Two themes emerged: (1) Experiences of the amputation and (2) Coping strategies to relate to a new norm.

THEME 1: EXPERIENCES OF THE AMPUTATION

Three categories emerged: (I) Facing the trauma/diagnosis, (II) Facing the amputation and (III) Coping with amputation in the acute phase. In the first two categories, both a physical and psychological dimension was identified. In the third category three aspects were described separately.

I. Facing the trauma/diagnosis

The accident occurred unexpectedly and suddenly. The impact of the trauma was so huge that the informants described feeling totally crushed. The sudden change from being healthy to being seriously injured/ill was overwhelming. The informants diagnosed with cancer also had to cope with a disease with a high mortality rate.

A. Physical dimension

The informants felt physically helpless, and dependent on help from others. This new situation meant feelings of frustration and was a source of irritation.

But just from one day to the other you are totally finished. That's the hard part. People that are sick, this is what I believe, for a long time, they carry their problems with them all the time. But this… it's such a big change… from one situation to the other, instantly, you see. That's really quite tough. On Friday I was up fixing the roof and on Sunday I am lying in the hospital and I can't do a bloody thing. That's what I mean. It's one hell of a change… So that… it's tough…But I was up there renovating, put on roofing felt and things like that on the garage on Friday. Then it happened on Saturday. Afterwards … well, then you were like completely finished the rest of the week, you know. Afterwards you couldn't do anything any more, that's what I was thinking, hell, now you are completely finished. (2PMS 16–17)

B. Psychological dimension

The informants had feelings of unreality. They also felt vulnerable and afraid.

Well,… hell I don't know… Then you felt… well… I felt kind of like… well, like a newborn baby, sort of… you might say… Totally helpless, that's how you felt… So that… Well… you hadn't grasped it yet, sort of… what had happened. Although you see it, you still don't grasp it… so to speak. And it… it happens so quickly, you see… So, I didn't understand… So, that… well, I felt, in a way, like I was completely newborn… Just lying there, sort of… (1PMS 7)

II. Facing the amputation

The amputation was perceived as an additional trauma to the accident/diagnosis.

A. Physical dimension

The informants perceived their body as strange and unfamiliar. What was left of the leg was swollen and not recognizable. They also described that they felt mutilated. Their body image was changed in a negative way. They tried to avoid situations where they would be looking at the whole body, for example through a mirror.

But then it, sort of… it took almost half a year before you sort of accepted the way it looked, you know. So that it, so to speak… you thought…what the hell does this look like… It was swollen and things like that. You barely wanted to touch it. So you thought, what the hell, this doesn't belong to me, does it …(2PMS 14)

Yes, but you see… when you get up… and you see… you are so… mutilated in a way… There is just one leg standing… well… It is so… and then the crutches and… that you need to carry with you all the time and… I think it looks… (1LKJ 15)

B. Psychological dimension

The informants had feelings of resignation as now there was nothing that could be done to save the leg. They also felt uneasiness with all the equipment being attached all over the body. The informants felt that the physical loss also had effects on the perception of being whole. They expressed feelings of emptiness and loss of self-image.

I know… I don't know… I felt empty in a way… I wasn't whole, you know… In a way I wasn't a whole human being… (1LKJ 14)

Well it… it had really stuck to me, I think… So it felt a little bit like the person inside me… Took away… that is, the man, or what shall I say… Well… the whole… the whole person was gone… Well, that is… the whole… I mean… that is, the perfect person… was gone. (1NMH 4)

III. Coping with amputation in the acute phase

Three aspects were identified: (A) Returning home for the first time, (B) Loss of function and (C) Loss of self-confidence.

A. Returning home for the first time

This aspect was described as a very tough experience both physically and psychologically. The informants were unprepared for the immediate comparison with what they used to be capable of when they were healthy. They had not foreseen that even very small things had become obstacles in this new situation. Coming home to an environment with unexpected problems due to weakness, e.g. managing to go up and down the stairs, was very hard. In comparison they felt safer in the hospital environment. The informants felt as if they had become a different person. They also felt that it was difficult to meet old friends and family. Especially the informants diagnosed with cancer felt these reactions as a result of additional chemotherapy treatment, which had further changed their physical appearance.

Yes, that was pretty hard… (laughs a little)*… It was really hard. It's not until now, the last six months that you have sort of… felt… felt normal around the house. But in the beginning it was hell, so to speak… it was like… well, you didn't feel at home still, although you were at home.*

Thanks to all the time you spent in the hospital, you know. And like… You thought that it was pretty hard… Well, all kinds of things. You couldn't go shopping and well, everything that you are not used to. And you couldn't… well, you couldn't sort of do anything in the beginning in a broad sense. You were happy to just come down the stairs. So it was pretty tough to come home, I mean when… You couldn't take a shower and… Well you couldn't even bloody stand up straight and stuff like that. And using stairs, that was really tough. I know the first time I wanted to go up the stairs, I had to bloody sit down on the steps and sort of drag myself up. So, you couldn't even sort of jump upstairs. You didn't have that strength. So that… And down to the basement, you had to sit on the steps and sort of slither down, you see. Well, that was really hard. So that… and then you had bandages and all sorts of crap and, well… so that… Well, I don't know. You were in a bad mood then too. All the time, that is. Hell, I don't know… well, you were in a bad mood. You thought, what the hell, you are like an eighty-year-old. Couldn't do anything. Almost got mad at yourself. You still wanted to go home… but I know in the beginning, let's say the first … after one and a half months, when you were at home, then… well… then you felt like you were safer at the hospital. You had that attitude. You felt safer at the hospital than at home, that is. Then things had gone to far. Then you rather wanted to go to the hospital than to be at home. Hell, I don't know, but you felt sort of safer there in a way. But then… well, then I got so tired of it all, so that… hospital and everything, so that… But it takes time to find… find yourself again. So that you can… well do everything at home and all that. But it was really hard the first time. It was… Well, it was hard just to stand up and cook food, you know. Everything like that. So you got mad because you couldn't do it and … well, everything like that. It was… really hard. You wanted to do things, but still you couldn't, you see. (2PMS 16)

B. Loss of function

The younger informants missed being playful and having freedom of movement, e.g. not being able to climb trees and to run. All felt that they were limited when moving. They missed being able to choose their own pace and to be physically spontaneous. They described that they had to do things differently than before or maybe refrain from doing them altogether. The informants also felt dependent on and limited by the prosthesis, and the loss of function was even more obvious when they took the prosthesis off.

Yes, for example… eh… to go outside maybe and climb trees and such… These are the type of things that irritates me… that… What I really would like to do for example. But it isn't sort of possible. It's such small things… like… that you don't sort of think about… But you still want to… But it… it's not very… so… To run… I mean to feel your hair being blown back… That was something that I wanted… But now… it took a while before I found out that I can use a bicycle. Then I still get the feeling… To get my hair sort of, blown backwards by my own effort, sort of… Now when I am bicycling I get that anyway… But then it felt… then I wanted to do it… but it… I don't think it is that bad anymore… It is stuff like that… stuff… such things that you don't really think about…It's sort of… such small things that…really are quite… easy… that you don't think about… you just do them… But which still … (1LKS 11)

But it takes time, right… So that it's nothing that sort of bothers me in that sense… that I can't sort of… do a lot of things. I guess it's basically that I sort of don't run. That's the biggest… well, how shall I put it… loss, or what to say, right… Particularly that I can't move at a pace of my own choice… (1CML 5)

C. Loss of self-confidence

The informants described the importance of getting their self-confidence back so as to be able to cope. It was so important that self-deception was used to overcome feelings of insecurity.

Yes, it… But you have to have, I think… Or else you can't cope with it… Can't handle anything… But still… I am a bit insecure really… so I have to have… still sort of… try to be as tough as possible, so that nobody can see how insecure I feel… that I am actually a bit insecure… It's rather things like that… that makes me do things to appear more than who I am… I don't know…Like I am… I'm not self-confident enough compared to what I want to be. But I still pretend that I am. So I'm deceiving myself to believe it. But as long as I can deceive myself, then I think it's fine, because then I believe that I do feel self-confident. And then I am… As long… But then I realize that I am deceiving myself. And then I lose it… (1LKS 13)

THEME 2: COPING STRATEGIES TO RELATE TO A NEW NORM

Here too, three categories emerged: (IV) The prerequisites of coping, (V) Coping strategies in everyday life and (VI) The import/consequences of amputation.

IV. The prerequisites of coping

The informants diagnosed with a tumour were all informed about the operation before the amputation. In this respect the informants described the difficulty of fully understanding the import and the consequences of the information they had received. Some informants felt that some information was not straightforward, but was given in a way aimed at lessening the significance. They felt that the meaning therefore was a bit hazy. The informants had no understanding of what it meant to be disabled and they found it difficult to prepare themselves for the amputation. They also felt reluctant to ask questions as they didn't know if they were ready to face up to and cope with the answers.

But at that time… Then I was 22 and was about to turn 23 that summer. And I mean… I didn't know anything about handicap. I had never met a handicapped person in… the normal sense. I mean, definitely not anyone who had lost a leg or something. And if you had been to Lund… you know… the orthotists worked down in the basement. You could look in through the windows… There was a small part of the windows sticking up. So you could look down to the workshop. And then you could see a lot of plaster and… well, loose… false legs, you might say. They had a lot of arms and legs that you could see. It certainly was a strange world, right… eeehh… so… well… So I was totally unprepared for… for this, what was about to happen. (1LKB 4)

I mean a little girl, who is nevertheless deep down afraid of what this will lead to and… Well, you don't ask the questions, you maybe don't ask the questions because you may be afraid of the answers. Well, I don't know. At least I didn't. (2LKB 4)

V. Coping strategies in everyday life

The informants used downward comparison, positive comparison and repression. They described how they had memory gaps and repetitive thoughts and questions, although not as frequently as in the acute phase. All the informants used downward comparison as a coping strategy, i.e. comparing yourself with those who are worse off than yourself.

But I don't think… I am pretty glad that I… so… that I'm alive and such, sort of… Many of my friends at the hospital, they are not alive anymore… (1LKS 8)

And the… as it was a plastic surgery department, then there were many whose situation was much worse… There was one burnt baby and stuff like that. Children with terrible deformities that were to be corrected, so to speak, to make them look acceptable or what to call it… No, there were many who were many times worse off … so that… It's a bit hard to feel sorry for yourself in that situation… if… or… Well, when you saw a lot of other things that were really unpleasant… I mean… A burn injury is never going to look nice again. And… you yourself are basically able to walk away from there afterwards… Then it was really hard for me to feel sorry for myself… (laughs a little)… *in that situation sort of.* (1JML 17)

Some also used the strategy of comparing themselves with someone who was imagined to be more fortunate or have a more advantageous situation.

It's probably… Well, it's at least a feeling I'm having… eh… I think that a man… maybe still gets a little… so to speak, without knowing this for a fact, admired, you know, if he is… daring and sort of… or if he does this, that he… publicly, and… in a way. I don't know. In the back of my head there's all that about heroes, war and all that. It's masculine. But a woman. No, no, no, no. There's nothing attractive about a woman who has lost her leg. (2 LKB 11)

Many of the informants had repressed a lot of what had happened and had gaps of memory.

Well, it… you quite simply put it away in a box. All the way in the back of your head. (2 LKB 6)

The informants described how thoughts and questions kept repeating themselves, but not so intensely as in the acute phase.

Like many others, I think… just this, you know… Why should this happen to me? and… and… well…eh… what else… then this thought comes up… What have you… What evil have I done for this to be happening to me, you know… (2NMH 2)

VI. The import/consequences of amputation

The informants were not prepared for being exposed to people staring and asking intimate questions, which was experienced as most unpleasant. They described how they tried to avoid this stigma by doing everything they could to blend in. The informants felt a strong need to hide and cover the amputated leg. They felt limited in choosing their recreation activities and they preferred hobbies that they could do at home. Most of them totally refused any activity that involved uncovering the amputated leg. The informants described the importance of being recognized and treated as an individual and not as a disabled person. Only one informant had accepted his situation. The others described the difficulty of accepting theirs. They felt that they could learn to live with it, but not accept it.

But I do go swimming… But I don't swim at public baths… or before I did, but I think… It's really hard and then… Everyone's looking all the time… In the beginning then… I didn't care. Then I thought it was more like fun… that I was noticed. But now I want to be sort of more like normal, and blend in, sort of. And it… I can't sort of do that. I think it… it's quite hard… But I do it at times… But I could never go to the public baths on my own… It wouldn't sort of be possible… To have all those eyes following you… It's impossible… (1LKS 8)

And it… it has probably a little bit to do with me not wanting to go swimming and such because… I just don't like to walk about with it naked… If I am wearing trousers, then I can go to *physical training without probl… then it doesn't show… sort of… but to have it uncovered and to enter a swimming pool, that… I wouldn't do that …*(1LKJ 6)

That's something I have been doing, getting hobbies that I can do at home… I'm totally crazy about all sorts of fish and snakes… So I have some snakes at home as well… It's nice and quiet at home… (1JML 11)

Comments: When the trauma/diagnosis was first encountered, the informants had feelings of unreality, helplessness and fear, which characterize the immediate shock reaction. This phase was then succeeded by a phase of avoidance and denial, which is also a normal pattern (Shontz, 1977; Cullberg, 1984; Lundin, 1992). In a rehabilitation setting the trauma should be encountered in small doses to avoid the ego being overwhelmed. This should be done by letting phases of re-encounter and avoidance replace each other, as suggested by several authors (Shontz, 1977; Walters, 1981). Denial was used, which is a strategy that supports emotion-focused coping (Lazarus, 1983). The repetitive thoughts and memories and the initial emotional numbness may be symptoms of a posttraumatic stress disorder (Fitzpatrick, 1999). Memory gaps may be a result of using repression, avoidance and denial. Avoidance reactions were used especially when first encountering the injured leg. One example was when one informant was confronted with a photograph of the injured leg before amputation. Another example was one only allowing video filming and the use of mirrors when the upper body was excluded.

All informants also coped with the acute situation by comparing with those less fortunate, making downward comparisons (Taylor, 1983; Taylor et al., 1983) or making positive comparisons (Pearlin and Schooler, 1978; Lazarus and Folkman, 1984; Folkman and Lazarus, 1985). Emphasizing the positive was found by Folkman and Lazarus (1985) to be a special form of emotion-focused coping, which facilitated problem-focused coping. Finding positive meaning has been linked to higher levels of perceived health and physical capabilities (Gallagher and MacLachlan, 2000) and lower levels of depressive symptoms (Dunn, 1996). The informants diagnosed with cancer perceived a meaning in the loss of their legs, as the amputation was regarded as a way of saving their lives (Taylor, 1983; Maguire and Parkes, 1998).

Self-confidence among our group of transfemoral amputees was strengthened mainly by use of downward comparisons, comparing with others more ill or more unfortunate. A strong self-confidence was perceived as the prerequisite for adequate coping to the point where self-deception was used to restore the self-image. Taylor (1983) also found that cancer patients focused on trying to regain control and strengthening their self-confidence.

The informants were unprepared for their reactions when they returned home. In this situation their newly adapted coping strategies collapsed. Feelings of dependence, loss of function and self-confidence were overwhelming in this situation. The informants were also unprepared for feeling stigmatized. The unpleasant staring of strangers and the exposure to intimate questions led the amputees to avoid crowds and made them reluctant to participate in any sport or recreation hobby which involved uncovering the amputated leg. To avoid this situation they took up hobbies that could be done at home. This change in lifestyle after amputation was also found in a study of 228 amputees (Burger and Marincek, 1997). All informants in our study expressed a wish to be recognized and treated like everybody else. Gallagher and MacLachlan (2001) also reported that the wish to appear and be "normal" was emphasized. Montgomery et al. (1996) found that disabled persons adjust to their life situation by de-emphasizing the importance of the physical functions affected by the disability and through habituation. An unexpected result was that only one of the informants had accepted his disability and the consequences of the amputation. The informants with cancer tended to accept the amputation as a life-saving action, but none had reached the acceptance level. However, according to Silver and Wortman (1980), this finding is not unusual.

General discussion

The normalized gait pattern and gait speed can be explained by improved gait technique and improved body awareness including integration of the prosthesis. Although none of the participants showed any apparent symptoms or otherwise signs of psychological illness, this combination of psychiatric physiotherapy treatment was chosen. All participants shared the same impaired gait pattern before treatment, in which the prosthesis seemed to be disconnected from awareness of body and movement. This kind of interpretation of the meaning of restrictions and deviations in movements is often used in psychiatric treatment, guiding the therapist in the choice of exercises (Feldenkrais, 1988; Mattsson and Mattsson, 1994; Mattsson et al., 1997; Lundvik Gyllensten et al., 1999).

The deliberate use of a conscious therapeutic approach was probably also a contributing factor to explain the remarkable outcome, though very hard to measure. The importance of warm support, empathy and respect shown by therapists in the psychological care of trauma patients has also been emphasized by several authors (Everstine and Everstine, 1986; Flegenheimer, 1992; Mohta et al., 2003).

The participants were unprepared for their reactions when they returned home. Feelings of dependence, loss of function and self-confidence were overwhelming, which is a common psychological reaction in amputees (Shontz, 1977; Racy, 1989; Maguire and Parkes, 1998). Lack of control may lead to emotional, cognitive and behavioural difficulties as well as loss of self-esteem although the victim is not responsible for the trauma/disease (Abramson et al., 1980; Taylor et al., 1983). The most offensive aspect of victimization is that it represents loss of value, status and resources (Taylor et al., 1983).

Patients' ability to cope with limb loss and to adjust to their body image appropriately has been shown to be independent of the period elapsed since the amputation, age, gender and the level of amputation (Pucher et al., 1999). In the present study all participants coped by comparing with those less fortunate, making downward comparisons (Taylor, 1983; Taylor et al., 1983) or making positive comparisons (Pearlin and Schooler, 1978; Lazarus and Folkman, 1984; Folkman and Lazarus, 1985). Finding positive meaning has been linked to higher levels of perceived health and physical capabilities (Gallagher and MacLachlan, 2000), lack of complaints (Pucher et al., 1999) and lower levels of depressive symptoms (Dunn, 1996). Self-confidence among our group of transfemoral amputees was strengthened mainly by downward comparisons, comparing with others more ill or more unfortunate.

Another contributing factor was probably that the treatment period was regarded as a process. The treatment period averaged 10 months (range 7–14). To learn a new movement pattern and motor control, without normal inputs from proprioceptors in joints, muscles, skin and foot-sole is an ongoing process (Shumway-Cook and Woollacott, 1995) of adapting to the amputation and the prosthesis, as well as facing social and other consequences (Wahlborg-Kamwendo, 1979; Engstrom and van der Ven, 1993). Although the treatment period is longer than conventional rehabilitation of amputees, the approximated cost of the total period of treatment was equivalent to less than half of the total cost for one prosthesis (Hermodsson and Persson, 1998).

All training took place outdoors regardless of weather, which probably was an added contributing factor to the remarkable outcome. This meant that training could be extremely varied, taking maximum advantage of the terrain, weather and environment. The choice of different environments also had positive, psychological effects. As in the study by Hagberg and Brånemark (2001), most of our participants had not been to a sandy beach, wood or similar recreation areas since the amputation. The environment itself contributed to creating a joyful atmosphere.

An amputated person consumes more energy than a non-amputee, and energy consumption increases with higher levels of amputation (Waters and Mulroy, 1999). Exercise intensity is therefore adjusted to the level of amputation in conventional rehabilitation. The higher the level of amputation, the lower the intensity during training as a result of the increased energy consumption (Wahlborg-Kamwendo, 1979; Ham, 1996). This may explain why the aims of conventional rehabilitation are basic daily activities and seldom include the participation level according to WHO (ICF, 2001). The combined treatment made it possible for the subjects to take full advantage of their skills in a social context. Before treatment all participants avoided social events where people gathered, e.g. going shopping or dancing, for fear of being pushed and losing their balance. The unpleasant staring of strangers and the exposure to intimate questions led the amputees to avoid crowds and made them reluctant to participate in any sport or recreation hobby which involved uncovering the amputated leg. Social discomfort has also been shown to be a significant predictor of depression (Rybarczyk et al., 1992).

The improved gait speed, the normalized gait pattern and the experience of skilfully handling different terrain and environments also may have had the effect that the participants felt less stigmatized socially. During the treatment period all these situations, formerly avoided, were spontaneously tried out and successfully managed by the participants—and they were having fun doing them. Balance confidence has been found to be an important factor associated with both social activity and mobility capability and performance (Miller et al., 2001). In our study balance confidence was not measured, but may have been a contributing factor since the participants reported feelings of increased control over the prosthesis as the training progressed.

For the seven participants who learnt to jog, this experience was exceedingly positive. They reported before treatment that the ability to jog was the function that they had missed the most. However, the goal of learning to jog was not to become a skilled jogger or sprinter. For such a purpose a special, individually adjusted prosthesis is required. The goal was to alternate gait speed and to have the ability, for example, to catch a bus if necessary, and this achievement gave a feeling of freedom of choice and improved quality of life.

The gait analysis measurements showed increased symmetry between the hip joints in the sagittal plane. However, in the transverse and frontal plane after treatment there was an increased asymmetry and a difference in timing. In spite of this, gait appeared to be more symmetrical, probably due to more symmetrical upper-body movements. Arm movements were included in the training and may also have contributed to the impression of increased symmetry. They were not measured and their influence on the walking pattern of the transfemoral amputees needs further investigation.

Using the VICON system for the gait analysis may have limited the interpretation of some results as the biomechanical model of VICON, described in VCM user's manual (1995), is based on healthy subjects. The construction of the energy-storing prosthetic foot, for example, is very different from the "normal ankle joint" and may therefore be difficult to measure with the VICON system. To be perfectly sure about the effect of the prosthetic foot, the biomechanical model should have been adjusted to reflect its design, which may be possible in future studies. Another variable which cannot be measured by the VICON system is the position of the femur in the socket during walking, which may have influenced some results. Other methods have been used to study these movements (Convery and Murray, 2000; Soderberg et al., 2003) and in future studies it may be possible to include these results in a new model.

The improved self-selected speeds chosen by the participants after training indicated improved walking skills. This was supported by a tendency to a decrease in the energy cost of walking at the improved comfortable speed chosen after training. When walking with the new, swifter, self-selected speeds after training, there was a significant increase in heart rate and oxygen consumption, which also indicated that the improved walking skills were not due to improvement in physical fitness but rather to improved ability of the participants to use their inherent metabolic resources. This finding was somewhat surprising—although the aim of the training programme was to improve walking skill and not general physical capacity—that the maximal aerobic capacity of the participants did not truly improve after training.

We invited all the amputees that were eligible at that time in our area. Because of their wide range in age and cause of amputation we chose to develop this method in a continuous uncontrolled series. However, in the future it would be of interest to evaluate this method by an unbiased observer in a controlled study.

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