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Muscle Activation Patterns in the Trans Tibial Amputee

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Honours Project NCPO



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LIST OF ABBREVIATIONS

TTA	transtibial amputee
AB	able-bodied
EMG	electromyography
IEMG	integrated electromyography
VL	vastus lateralis
BF	biceps femoris
MVC	maximum voluntary contraction

ABSTRACT

Atrophy of the amputated limb thigh musculature is commonly observed in the transtibial amputee. The purpose of this investigation was to determine the relationship between this observed atrophy, and muscle activation patterns which occur during common daily activities. The tasks investigated were level walking, stair ascent, stair descent, rising and sitting. Ten active unilateral transtibial amputee (TTA) subjects and ten able-bodied (AB) subjects participated in the study. Surface electrodes were used to record EMG activity of the quadriceps and hamstrings muscles, as the subject completed the set tasks. The peak amplitude EMG was analysed and compared between limbs for each activity.

The AB subjects displayed symmetry of muscle activation in all activities. In level walking the TTA subjects also demonstrated similar peak quadriceps activation between amputated and sound limbs. Postural compensations and altered thigh muscle activity were observed in stair ambulation. Although variations occurred, the peak muscle activation in the amputated limb was not significantly different to the sound limb.

During the activities of rising and sitting, the peak activation in the amputated limb quadriceps was substantially reduced in comparison to the sound limb ($p < 0.001$). This result may be due to the decreased lever arm of the tibial remnant, or to limitations of the prosthetic socket. The inability to flex the knee past ninety degrees, or pain at the anterodistal tibia due to pressure on the socket, will result in the transfer of most body weight to the sound limb during rising. The activities of rising and sitting are involved in the maintenance of normal strength in the AB individual. The sound limb dominance displayed by the TTA during these activities results in a reduced activation of the amputated limb quadriceps. A lack of sufficient muscle stimulation leads to disuse atrophy of the affected muscles. Although gait is an important functional requirement for the transtibial amputee, it is vital that other common activities are considered during prosthesis design and manufacture.

STATEMENT OF AUTHORSHIP

Except where reference is made in the text of the thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma.

No other person's work has been used without due acknowledgment in the main text of the thesis.

This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution.

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CHAPTER 1: INTRODUCTION

Thigh muscle strength is essential for the able-bodied individual to achieve a functional level of mobility. The quadriceps muscles provide stability and progression during ambulatory activities, as well as during other common daily tasks. The transtibial amputee, in addition to these activities, requires adequate thigh muscle strength in order to gain optimum control of the prosthetic limb.

Following transtibial amputation, the loss of anatomical structures below the knee results in compensatory mechanisms occurring in more proximal muscles and joints. Efficiently functioning muscles about the knee and hip joints appear to be beneficial to the transtibial amputee in the completion of daily tasks. During post-operative rehabilitation, the amputee generally undergoes strength training of both the sound and amputated limbs. This training is an important factor in minimising the effects of post-operative immobilisation on the involved muscles, and also in achieving a functional level of independence within the constraints of the residual neuromuscular system.

As the amputee returns to a normal level of activity, and becomes an experienced prosthesis wearer, it is expected that the amputated limb would approach a strength similar to the sound limb. However, the amputated limb

thigh musculature in transtibial amputees frequently displays signs of persistent muscle wasting. This atrophy is commonly associated with a reduction in strength and endurance of the involved muscles.

The observation of thigh muscle atrophy has been noted by several previous authors (Renström, Grimby, Morelli, and Palmertz, 1983a; Klingenstierna, Renström, Grimby, and Morelli, 1990; Pereira and Kafalas, 1995; Isakov, Burger, Gregoric, and Marincek, 1996). However, the precise cause remains unclear, and the prevention of this atrophy is yet to be achieved.

The aim of this investigation is to determine the relationship between the observed atrophy, and the adapted motor patterns occurring in the lower limbs during normal daily activities. A greater understanding of this relationship will allow further development in this area and, in the future, an improved outlook for the transtibial amputee.

CHAPTER 2: LITERATURE REVIEW

2.1 THIGH MUSCLE ATROPHY

Atrophy of the amputated limb thigh musculature is commonly observed in the transtibial amputee. The precise cause of this atrophy, as well as the effects it has on gait, muscle fatigue and neuromuscular adaptations, are at present unclear. A study by Renström, Grimby, Morelli and Palmertz (1983a) has provided a comprehensive analysis of this observed atrophy.

In an investigation of ten transtibial amputees, atrophy was evaluated by the use of computed tomography and muscle biopsy techniques, and the obtained measurements were evaluated in comparison with the sound limb. The cross sectional area of the whole thigh in the amputated limb was found to be 86 percent of the area at the corresponding level in the non-amputated limb. The cross sectional area of the specific thigh muscles indicates that the majority of the atrophy occurs in the quadriceps muscle group. This muscle was only 66 percent of the cross sectional area of the sound limb, whereas the hamstrings muscle group was 80 percent of the same measurement on the sound limb.

Previous investigations into immobilisation or disuse have also reported a greater reduction in knee extensor musculature compared with knee flexor musculature (Häggmark, Jansson and Eriksson, 1981; St Pierre and

Gardiner, 1987). This is due to the vasti extending across one joint, as opposed to the hamstrings which extends across two joints, and to its antigavity role (Appell 1990; Hather, Adams, Tesch and Dudley, 1992; Gordon and Mao, 1994).

Use of computed tomography to evaluate the cross sectional area of the total thigh muscles demonstrated the amputated limb to be 76 percent of the sound limb. This result indicates that the reduction of the cross sectional area of the amputated limb thigh muscles was proportionally greater than the reduction in circumference (Renström et al, 1983a). The external thigh circumference is not a totally accurate measure of thigh muscle atrophy, as it is likely to conceal large differences in quadriceps cross sectional area. This may be due to an increase in subcutaneous tissue thickness, as well as proliferation of connective tissue (Ingemann-Hansen and Halkjaer-Kristensen, 1977; Appell 1986 and 1990; Häkkinen, 1994). The difference in cross sectional area of the femur between amputated and sound limbs was minimal.

In order to assess the atrophy of specific muscle fibres, muscle biopsies were taken from vastus lateralis of both amputated and non-amputated limbs. These were taken at the same level as the computed tomography scan for cross sectional area results. It was reported that the mean fibre area of the vastus lateralis of the amputated limb was 74 percent of the mean fibre area of the non-amputated limb (Renström et al, 1983a). The results indicated that the main cause for changes in muscle volume was reduction in fibre size.

The muscle fibre types can be further divided into Type I - slow oxidative fibres, Type IIA - fast oxidative fibres, and Type IIB - fast glycolytic fibres. These fibre types differ in their maximal velocities of shortening, their primary energy pathways, and their rate of fatigue. Slow twitch fibres are very resistant to fatigue which allows them to maintain contractile activity for long periods with little loss of tension, whereas fast twitch fibres fatigue rapidly (Vander, Sherman and Luciano, 1986). Most muscles have all three types interspersed with each other. It is known that the postural muscles of the lower limbs contain large numbers of fatigue resistant slow fibres to support the weight of the body (Vander et al, 1986).

In the vastus lateralis muscle, it was reported that the distribution (or percentage) of Type I fibres is reduced in the amputated limb when compared to the non-amputated limb, and there is a corresponding increase in the distribution of Type II fibres. This increase is more prevalent in Type IIB fibres which, as previously mentioned, have the lowest fatigue resistance capacity.

Renström et al (1983a) stated that a reduction in Type I fibres has been reported in muscles following immobilisation, or due to pain. Whether immobilisation leads to preferential atrophy of one type of muscle fibre remains unclear, as many contradictory results have been reported (Duchateau and Hainaut, 1990; Hather et al, 1992; Veldhuizen, Verstappen, Vroemen, Kuipers and Greep, 1993; Häkkinen, 1994). There is greater

evidence, however, to suggest that Type I fibres are primarily affected (St Pierre and Gardiner, 1987; Appell, 1990).

During the post-amputation period, immobilisation generally occurs due to pain and healing of the amputation site. A reduction of Type I fibres *may* occur at this time. Once the amputee begins ambulating, it may be expected that this slow muscle fibre distribution will approach the pre-amputation level. However, it is evident that walking with a prosthesis alters the gait pattern (Breakey, 1976; Winter and Sienko, 1988). This modified gait pattern may influence the function of the muscles, and thus the afferent impulses from the muscles and joints which might be of importance in the maintenance of Type I fibres (Renström et al, 1983a; Duchateau and Hainaut, 1990). Over a long period, an altered fibre distribution between Type I and Type II fibres may be expected, and the rate of fatigue of the involved muscles will be affected (Booth, 1987; van Lent, Drost and Wildenberg, 1994; Ploutz-Snyder, Tesch, Crittenden and Dudley, 1995).

2.2 THIGH MUSCLE STRENGTH

Renström, Grimby and Larsson (1983b) also conducted a study into thigh muscle strength in a transtibial amputees. It was reported that both isometric and isokinetic knee extension and flexion strength in the amputated limb was significantly lower than in the non-amputated limb, a finding supported by Isakov, Burger, Gregoric and Marincek (1996). In addition, Isakov et al reported a correlation between residual limb length and maximum strength available in the amputated limb thigh musculature.

The sound limb has been reported to display similar strength values as those reported in the normal population of corresponding ages. In healthy subjects, the quadriceps muscle group is almost twice as strong as the hamstrings group. However, Renström et al (1983b) found that in the amputated limb, knee extension and flexion strength were of a similar magnitude. This indicates that knee extension strength in the transtibial amputee was relatively more reduced than knee flexion strength. This result is related to the greater degree of atrophy demonstrated in the quadriceps muscle group.

Although the observed atrophy is associated with a decrease in strength, this reduction in strength of the thigh muscles was found to be greater than the reduction in cross sectional area in the amputated limb. Therefore, in addition to the measured atrophy, other factors may be of importance in the reduction of muscle strength. It has been suggested that *a decrease of*

muscle activation through a diminished motor unit discharge frequency and/or motor unit recruitment and synchronisation may contribute to the weakness (Renström et al, 1983b). Neural factors have been demonstrated to play an important role in the modification of strength values (Häkkinen and Komi, 1983; Komi, 1986; Narici, Roi, Landoni, Minetti and Cerretelli, 1989; Dudley, Duvoisin, Adams, Meyer, Belew and Buchanan, 1992; McComas, 1994).

It has been demonstrated that motor unit recruitment patterns can be influenced by training. Improvements in muscle strength are accompanied by increases in EMG of the involved muscle. This may be explained as an increased recruitment of synchronously-contracting motor units (Häkkinen and Komi, 1983; Appell, 1990). A reduction in EMG activity is then demonstrated as the contribution of hypertrophic factors is gradually increased. The corresponding mechanisms also appear to occur during disuse. The initial decrease in strength may be due to a reduction in the neural activity, with a gradually increasing contribution of muscle atrophy (Häkkinen and Komi, 1983; Komi, 1986; McComas, 1994).

2.3 STRENGTH TRAINING

It has been suggested that the observed thigh muscle atrophy and related decrease in muscle strength is a possible cause of gait deviations in the transtibial amputee population. Hsu, Perry, Gronley and Hislop (1993) reported that unilateral weakness of the quadriceps muscle causes pathological gait patterns with compensatory locking of the stance knee in hyperextension. Renström et al (1983b) suggested that knee extension and flexion strength in the amputated leg with prosthesis is correlated to step length and maximal walking speed. Whether these correlations, as reported by Renström, indicate a causal relationship remains questionable. In order to investigate this concept further, the effect of thigh muscle strength training in the transtibial amputee has been studied.

In 1990, Klingenstierna, Renström, Grimby and Morelli developed a strength training programme for a group of eight transtibial amputees utilising isokinetic training of knee extensors and flexors on both amputated and non-amputated limbs. Following an average of twenty training sessions, the ratio of thigh muscle strength in the amputated to non-amputated limbs was increased from 50 to 60 percent. Only a slight increase was observed in the non-amputated limb. The increases in strength were larger in the knee extensor muscles than knee flexor muscles, seemingly related to the degree of atrophy noted in the quadriceps muscle group.

The mean cross sectional area of vastus lateralis muscle fibres demonstrated an increase in Type II (fast twitch) fibres, but was of a smaller magnitude than the strength increase (Klingenshierna et al, 1990). It was stated that the increased strength may have been, in part, explained by a more ample and synchronous activation of motor units after training. However, the investigation failed to find any improvements in functional ability after training, recorded as walking velocity on level surfaces or stairs, as was originally predicted.

An investigation into quadriceps strengthening of transtibial amputees was developed by Periera and Kafalas (1995). A single subject, who exhibited severe thigh muscle atrophy and weakness, participated in a six week programme, during which time both amputated and sound limbs underwent isokinetic training. After training, the strength values of the amputated limb approached those of the non-amputated limb. This increase in strength, however, did not result in changes in knee kinematics or kinetics during gait.

A possible explanation offered by the above authors is that the gait pattern was habitual and gait training would be required in order for the subject to utilise the increased strength available as a result of the quadriceps strengthening programme. Another interpretation of the results is that the quadriceps weakness observed is due to disuse, and further that the amputee adopts a gait pattern in which extensor moments are minimised. In order to investigate this concept, it is necessary to examine the residual motor patterns and their relationship to thigh muscle atrophy.

In 1970, Müller reported that strength is normally regulated by stimuli from muscle contractions involved in daily activities, which occasionally may not be sufficient to maintain strength at constant level. In the absence of any contraction of a muscle, strength decreases by approximately five percent per day. It was reported that one contraction a day at half the maximum strength is enough to prevent this decrease. More recently, Jones and Round (1990) stated that ten repetitions a day at loads greater than 60-70 percent of maximum strength will produce a small but steady increase in strength. However a cycle of disuse may result in prolonged extreme atrophy of potentially useful muscles. It was suggested that in pathological gait, one sided inactivity, which may become habit, can result in a progressive decrease in strength due to lack of sufficient training stimulus. McComas (1993) reported that “all the adaptations of strength and endurance training, and those of everyday living, are reversible if the muscles are no longer used to the same extent”.

2.4 TRANSTIBIAL AMPUTEE GAIT

It has been demonstrated that increases in thigh muscle strength do not appear to result in improvement in clinical function or gait patterns of the transtibial amputee. It has also been suggested that the observed quadriceps atrophy may be due to disuse. It may be postulated then that the gait deviations displayed by the transtibial amputee are contributing factors to the thigh muscle atrophy.

A number of authors have examined the gait patterns of transtibial amputees and certain altered gait characteristics may be identified. In comparison with able bodied individuals, transtibial amputees demonstrate a reduced self selected walking cadence and velocity, as well as an increased energy expenditure at a matched velocity (Donn and Roberts, 1992; Barth, Schumacher and Sienko-Thomas, 1992; Lemaire, Fisher and Robertson, 1993). Among the asymmetries present, is a decreased step length for the natural limb, due to the loss of the ankle musculature and reduced push off capabilities on the prosthetic limb. A longer swing period for the prosthetic limb is also observed (Barr, Siegel, Danoff, McGarvey, Tomasko, Sable and Stanhope, 1992). This may be due to increased stability and therefore a preference for the sound limb, or to other factors such as a decreased period of oscillation due to the lighter mass of the prosthesis (Jans, 1994). Consequently, single limb support time is reduced on the prosthetic limb when compared to the sound limb (Breakey, 1976).

It has been stated by Radcliffe (1962) that since the anatomical knee mechanism is unaffected by a transtibial amputation, it is reasonable to expect such an amputee to walk with a normal knee action. However, knee motion and forces acting about the knee do not display a “normal” pattern in the prosthetic limb of the transtibial amputee.

It has been noted by many authors that the transtibial amputee displays reduced knee flexion in stance compared with able-bodied subjects. Moreover, the affected limb is found to remain predominantly in extension throughout stance (Breakey, 1976; Barr et al, 1992). In able-bodied subjects an extensor moment at the knee is generally observed during stance phase. This is found to decrease in the prosthetic stance phase of transtibial amputee gait (Winter and Sienko, 1988). Single limb stance with a reduced knee flexion angle has been demonstrated to require little quadriceps force. With the knee in full extension, zero active quadriceps force was reported by Hsu et al (1993). Many authors have even reported the occurrence of a continual flexor moment at the knee during gait in the transtibial amputee (Torburn, Perry, Ayyappa and Shanfield, 1990; Gitter, Czerniecki and DeGroot, 1991; Barr et al, 1992).

2.5 MUSCLE ACTIVITY IN NORMAL GAIT

The observed knee action during gait is dependent upon the muscles which act about the knee joint. In order to assess the patterns of the amputated limb musculature, a knowledge of relevant muscle action in able-bodied gait is required.

Just prior to initial contact the hamstrings muscle group is active and this muscle activity continues into early stance. Following heel contact the knee flexes rapidly due to the ground reaction force passing posterior to the knee axis. The activity in the hamstring group continues, but with decreased magnitude, while an eccentric contraction is rapidly developed in the quadriceps. This quadriceps action is necessary to restrain flexion at the knee and thereby preserve stability (Culham, Peat and Newell, 1986; Hsu et al, 1993).

Controlled knee flexion continues into mid stance, reaching a maximum at approximately twenty percent of the gait cycle. Following weight acceptance, a decrease in the level of quadriceps activity occurs. As momentum carries the body forward over the stabilised tibia, the line of action of the ground reaction force moves anterior to the knee joint resulting in passive knee extension. The quadriceps are no longer needed to stabilise the knee, and they become relatively silent by mid stance (Culham et al, 1986). Minimal muscular activity occurs in the muscle groups acting about the knee joint

throughout the remainder of stance phase. During much of swing phase the limb behaves like a passive pendulum. At terminal swing, the limb begins active deceleration by contraction of the hamstrings eccentrically. This action efficiently slows both hip flexion and knee extension. The knee then prepares for weight acceptance by early quadriceps activity (Rose and Gamble, 1994).

The above mechanisms and controlled motor patterns are necessary to ensure that the centre of gravity follows a smooth pathway during gait. This is commonly thought to require the least expenditure of energy in normal human walking (Saunders, Inman and Eberhart, 1953). Pathological gait may be viewed as an attempt to preserve as low a level of energy consumption as possible by compensatory motions at unaffected levels (Saunders et al, 1953). It is apparent from biomechanical analysis that adaptations by the residual neuromuscular system take place (Winter, Olney, Conrad, White, Ounpuu and Gage, 1990).

2.6 MUSCLE ACTIVITY IN AMPUTEE GAIT

A number of electromyographic studies have been performed in order to determine motor patterns in transtibial amputee gait.

Duration of EMG activity in amputee gait has been investigated by Breakey (1976). Comparison of sound to prosthetic limbs in this study revealed little difference in duration of thigh muscle action in gait. A study by Pinzur, Asselmeier and Smith (1991) reported that active transtibial amputees were able to maintain quadriceps activity and increase hamstrings activity in the prosthetic limb, in comparison to the sound limb. However limited walking transtibial amputees displayed decreased muscle activity in both muscle groups in the prosthetic limb. It was suggested by the authors that limited walking transtibial amputees do not functionally utilise the preserved knee joint and quadriceps muscle to their full potential.

An investigation by Culham et al (1986) reported that the muscle activity of the non-amputated limb was similar to that reported for normal individuals. The muscle activity in the amputated limb, however, was demonstrated to be prolonged in both quadriceps and hamstrings muscle groups in comparison to the sound limb. This prolongation of quadriceps and hamstrings activity during stance is thought to be related to the absence of the restraining effect of soleus acting (indirectly) on the knee joint. In normal subjects, as discussed previously, the line of action of the ground reaction force passes

anterior to the knee and hip resulting in passive extension at these joints. Prolonged muscle action may be required to actively extend the knee and hip, as the lack of dorsiflexion may provide some resistance to the natural forward progression of the body. Early heel rise could also be another factor which tends to decrease stability and may result in prolonged muscle activity.

Winter and Sienko (1988) published a comprehensive biomechanical investigation into the altered motor patterns and asymmetry of transtibial amputee gait. Kinetic and EMG results demonstrate considerably modified residual muscle activity compared with normal data. The graph of EMG activity presented displays greatly increased levels and duration of thigh muscle activity. It was stated that hyperactive hip extensors during early and mid stance compensated, partially, for the lack of energy generation by the plantar flexors at push off. This above normal hamstrings activity results in an excessive knee flexor moment. In order to negate the resultant moment, the knee extensors become hyperactive. This co-contraction of quadriceps and hamstrings is reported to create a knee moment which remains close to zero throughout stance. However, similar results of hyperactive quadriceps and hamstrings have not been replicated or reported elsewhere in the literature.

Many studies investigating EMG of transtibial amputee gait have indicated that increased duration of thigh muscle activity is due to a lack of ankle motion and/or energy generation at push off (Breakey, 1976; Culham et al, 1986; Winter and Sienko, 1988; Pinzur et al, 1991). The effect of dynamic elastic response prosthetic feet on proximal muscles and joints has been

investigated. Barth et al (1992) reported no significant differences in the six different prosthetic feet tested in the study. Torburn et al (1990) found no significant differences in intensity or phasing of EMG activity between five prosthetic foot types.

Previous literature of thigh muscle activity in the transtibial amputee generally reports prolonged muscular activity occurring both in the quadriceps and hamstrings muscle groups in comparison to the sound limb. This co-contraction was reported to provide increased stability for the prosthetic limb, and also to compensate for lost ankle plantarflexor activity. Winter and Sienko (1988) have also reported excessive levels of EMG activity. These results, suggesting increased muscle contraction, do not appear consistent with the thigh muscle atrophy commonly observed in the transtibial amputee. In an unpublished investigation, Jarrott and O'Keefe (1995) observed slight decreases in peak muscular activity in the amputated limb compared to the sound limb during the gait cycle.

It has been hypothesised that gait deviations displayed by the transtibial amputee may result in disuse atrophy of the amputated limb. However, most studies to date have reported EMG levels only slightly less than or greater than EMG levels in the sound limb. Duration of muscle activity appears to be increased in amputees. Changes in EMG patterns during walking do not appear to provide an explanation for the disuse atrophy observed in transtibial amputees. However, most of the previous studies have investigated level ambulation. It may be that although the amputee maintains almost normal

thigh muscle activation during level walking, a discrepancy between sound and prosthetic limbs may be observed during other activities which utilise thigh muscle contractions. Furthermore, it is possible that reductions in activation during more demanding tasks are primarily responsible for the disuse atrophy observed.

2.7 COMMON ACTIVITIES

One common activity which utilises thigh muscle activity may be stair ambulation. Previous investigations in able bodied subjects have revealed that thigh muscle activity is greater in stair ascent than during level ambulation (Lyons, Perry, Gronley, Barnes and Antonelli, 1983; McFadyen and Winter, 1988; Ciccotti, Kerlan, Perry and Pink, 1994). This is evident for the quadriceps muscle group (Shinno, 1971; Andriacchi, Andersson, Fermier, Stern and Galante, 1980; McFadyen and Winter, 1988; Ciccotti et al, 1994).

During stair ascent increased quadriceps muscle activity is required to provide stability for the flexed knee on the above step (Zachazewski, Riley and Krebs, 1993; Ciccotti et al, 1994). The knee extensors, especially vastus lateralis, are required to generate energy by concentric action to enable progression of the body (McFadyen and Winter, 1988). The plantar flexor musculature on the step below is not required for push off as during level walking. Hamstrings activity has been demonstrated to be minimal during stair ambulation (Shinno, 1971; Andriacchi et al, 1980; Zimmermann et al, 1994).

There is general agreement that during stair descent greater inherent stability is displayed (Zachazewski et al, 1993), and muscle activity is either reduced (Lyons et al, 1983) or similar to that occurring in level walking (Ciccotti et al, 1994). The quadriceps muscle group is required to provide progression, as in stair ascent, however an eccentric contraction is involved. The knee

extensors of the limb on the above step absorb energy and lower the body by a controlled lengthening to stabilise the knee joint (Joseph and Watson, 1967; Freedman, Wannstedt and Herman, 1976; McFadyen and Winter, 1988). Limb support at this time is not dependant on hip extensor action and therefore the hamstrings muscle group remains relatively quiet (Lyons et al, 1983).

Another activity which may influence thigh muscle activation is rising from a seated position. The action of rising has been found to activate the quadriceps muscle almost exclusively, with the hamstrings muscle being activated only to a low level. Rising exercises were demonstrated to increase strength in the quadriceps muscle group (Schüldt, Ekholm, Németh, Arborelius and Harms-Ringdahl, 1983).

A recent investigation into amputee gait on stairs has reported a gait which deviates from normal (Torburn, Schweiger, Perry and Powers, 1994). Significantly more time was spent on the sound limb resulting in an asymmetrical pattern of ambulation. Forward trunk lean was found to augment forward progression during stair ascent. During stair descent a number of the transtibial amputees investigated “basically hopped down the stairs” at prosthetic toe off. This was attributed to a lack of adequate ankle range of motion in the prosthesis. Perry and Shanfield (1993) reported that a very high level of activation is required in the quadriceps muscle group in order to control forward motion during descent over the prosthetic limb. Compensatory gait strategies resulted in altered muscular activity for the

transtibial amputee during stair ambulation (Powers, Boyd, Torburn and Perry, 1996).

It may be feasible that activities such as stair ambulation and rising from a seat provide a stimulus for maintaining, if not increasing, muscle strength in the thigh muscles. The quadriceps muscle group is required to provide progression of the body during both stair ascent and descent, as well as during rising. A preference for the unaffected limb by the transtibial amputee may result in less contraction, and therefore less stimulation, of the amputated limb quadriceps muscles. This may contribute to the observed atrophy due to disuse of the knee extensor musculature.

CHAPTER 3: HYPOTHESES

The causes of the observed thigh muscle atrophy in transtibial amputees remain unclear. Strength training of the involved muscles does not appear to improve the clinical function or gait of the amputee. It is postulated that the altered gait characteristics commonly displayed by the transtibial amputee contribute to this atrophy. This may occur due to disuse, particularly of the quadriceps muscle group.

Activities in which the amputee is involved throughout the course of a day may have a greater influence on patterns of muscle activation than during level walking. Activities such as stair ambulation and rising from a seated position have been demonstrated to employ increased muscle activation in able-bodied subjects and may be involved in the maintenance of normal strength.

The hypotheses for the investigation are that thigh muscle activity of the amputated limb, in the transtibial amputee, displays relatively similar patterns and peak levels of EMG to the sound limb, and to able-bodied subjects during *level* ambulation. However, during activities such as stair ascent, descent, rising and sitting, it is hypothesised that the peak thigh muscle activity in the prosthetic limb will be reduced in comparison to the sound limb. This difference between amputated and sound limbs is expected to be greater than the difference naturally occurring between the limbs of able-bodied subjects.

CHAPTER 4: METHOD

4.1 SUBJECTS

Ten active male subjects with unilateral transtibial amputations were selected to participate in this investigation. The subjects had no existing medical problems, or any associated complications that would influence gait at the time of testing. One participant (subject no. 7) ambulated using a single point stick for assurance. The remaining nine transtibial amputee (TTA) subjects were independent ambulators. The residual limb of all subjects displayed no volume fluctuations or skin abrasions, and was free of pain. All subjects were experienced prosthesis wearers and used their prosthesis during all activities throughout the day.

The cause of amputation was trauma in seven subjects. The remaining three subjects had amputations due to cancer, Charcot's joint, or amputation secondary to congenital deformity. The mean age of the transtibial amputee group was 41.9 ± 16.7 years (range 25 - 73), and mean time since amputation was 10.9 ± 17.0 years (range 1 - 54). The prosthesis used in the investigation was the subject's own, and all participants had used their current prosthesis for a minimum of two months prior to the study. Relevant subject details, including the type of prosthesis worn, are displayed in Table 1.

AMPUTEE SUBJECT DETAILS						
Subject No.	Age (yrs)	Weight (kg)	Height (cm)	Time post - amp. (yrs)	Cause of amputation	Prosthesis type
1	42	115	181	6	trauma	PTB-cuff & waist belt, multiaxial foot
2	61	99	183	3	cancer	PTB-SC, Seattle foot
3	40	74	170	2	trauma	PTB-cuff, multiaxial foot
4	26	85	178	3	congenital	PTB-SC, Seattle foot, multiflex ankle
5	25	98	170	1	trauma	silicone socket, AirStance pylon, Seattle foot, torque absorber
6	43	80	177	27	trauma	silicone socket, AirStance pylon, Seattle foot
7	55	103	183	2	Charcot	PTB-cuff & neoprene sleeve, multiaxial foot
8	29	85	182	2	trauma	silicone socket, Vertical Shock Pylon / Flex foot
9	73	76	173	54	trauma	PTB-cuff, SACH foot (exoskeletal)
10	25	90	180	9	trauma	silicone socket, uniaxial foot (exoskeletal)
Mean	41.9	90.5	177.7	10.9		
SD	16.7	13.1	5.1	17.0		

Table 4.1. Transtibial amputee subject information.

The control group consisted of ten able-bodied subjects, six male and four female. All were fit and healthy individuals, with no musculoskeletal or neurological impairment which would affect their gait. The mean age of the control group was 37.1 ± 12.2 years (range 21 - 53). A summary of able-bodied (AB) subject details is included in Table 2.

All subjects were required to sign a statement of informed consent prior to participating in the investigation (Appendix 1).

ABLE-BODIED SUBJECT DETAILS				
Subject No.	Sex	Age (yrs)	Weight (kg)	Height (cm)
11	F	21	60	166
12	M	21	95	185
13	M	22	74	180
14	F	46	67	160
15	M	50	70	173
16	M	40	91	180
17	M	39	105	183
18	M	34	83	183
19	F	45	66	157
20	F	53	51	155
Mean		37.1	76.2	172.2
SD		12.2	16.9	11.7

Table 4.2. Able-bodied subject information.

4.2 INSTRUMENTATION

Electromyographic (EMG) signals were recorded using surface electrodes (figure 1). EMG data was preamplified at the electrode site with the amplification level adjustable at the backpack located around the subject's waist (figure 2). Data was transmitted through a coaxial cable to an MA 100 Interface Unit (Motion Lab Systems, Inc.), where the signal was fully rectified and filtered between 20-40Hz, to provide a linear envelope representative of the EMG signal. The data was linked to a Pentium 90MHz computer, and a NI 8 channels Lab-PC+ Data Acquisition (DAQ) Card, where the data was collected and stored for further processing. Signals were sampled at 250Hz at ten seconds per activity. Calibration data was collected on completion of the activities by pressing the calibration button feature in the backpack. Once calibrated the signal was passed through a 8Hz, second-order low-pass Butterworth filter. Collection, analysis and storage of all signals was performed using LabVIEW version 4.0 software (National Instruments).



Figure 4.1. Surface electrode used to measure EMG activity.

The footswitch data was used as trigger points to distinguish between the strides. When footswitch data was not available the individual activity was visually inspected and trigger points were placed by one operator for the entire exercise. This ensured consistent results and prevented different subjective inputs from the trigger points. All the required steps or single cycles of an activity were selected and classified into “dominant” and “non-dominant” data files.

Strides or cycles for the individual were normalised to 100 percent, and the area under the average curve for individual subjects was taken (integrated EMG, or IEMG). This provided the total muscle activation for each activity. The peak for each individual stride was also extracted then averaged to obtain the mean peak activity for each limb of the subject. This prevented unaligned peaks from being removed during the averaging process. Using a spreadsheet, the data for each subject was manually analysed, and then pooled across all subjects to obtain an average value for muscle usage in each group.

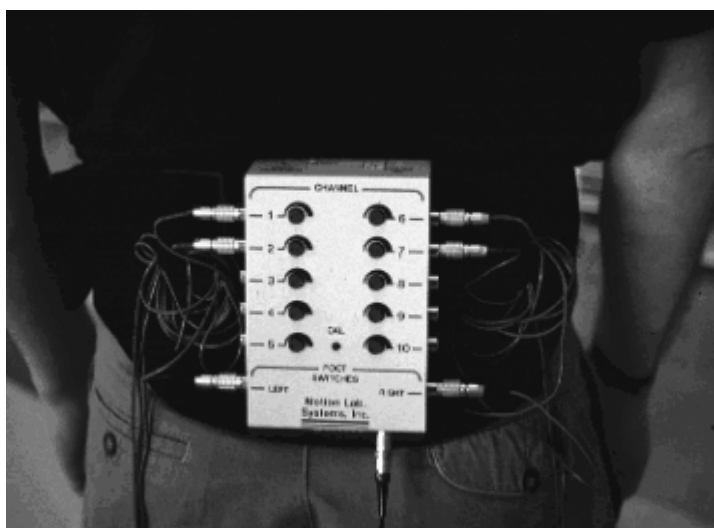


Figure 4.2. A backpack worn around subject's waist allowed adjustment of EMG signals and calibration of data.

4.3 PROCEDURES

Electromyographic activity of the quadriceps and hamstrings muscles was recorded bilaterally using four surface electrodes. The electrodes were placed longitudinally over the muscle belly of *vastus lateralis* (VL) and long head of *biceps femoris* (BF), in accordance with standard electrode placements as detailed by Winter (1988). Care was taken to ensure consistent electrode placement symmetrically between limbs and across all subjects.

- Vastus lateralis - over the greatest area of muscle bulk just lateral of the rectus femoris on the distal half of the thigh.
- Biceps femoris - midway on a line between the ischial tuberosity and the head of the fibula.

Circumferential measurements were taken bilaterally at the height of the VL electrode placement using a tape measure (details in Appendix 2). The able-bodied participants were asked to subjectively choose which lower limb was considered their *dominant* leg, for subsequent analysis of the data.

Prior to placing the electrode on the skin, the area was shaved and cleaned with a seventy percent alcohol solution to reduce resistance. The surface electrodes were taped in the appropriate position on the thigh, then wrapped

circumferentially using a foam underwrap followed by an adhesive cloth tape. Care was taken to ensure firm contact and minimal movement of the electrode over the muscle belly during completion of the activities.

Pressure sensitive footswitches were taped inside the heel of the subject's existing footwear, to provide the timing of heel contact for subsequent analysis of the walking data. Subjects were given time to become accustomed to wearing the equipment before the commencement of data collection.

The investigation involved the completion of five normal activities by each subject. These activities included:

- level walking
- stair ascent
- stair descent
- sit-to-stand
- stand-to-sit

Rest periods were encouraged between activities in order to eliminate the influence of muscle fatigue on the EMG signals.

4.3.1 Level Walking

Thigh muscle activity was recorded during gait as the subject walked along a 15m walkway in the gait laboratory, at a self-selected comfortable velocity. Ten seconds of data was collected at each trial, and two successful trials were obtained from each subject. After elimination of any acceleration or deceleration effects, ten complete strides per subject were obtained for analysis. This number of strides has been demonstrated to be a very reliable indication of muscle activity in gait (Arsenault, Winter, Marteniuk and Hayes, 1986b).

4.3.2 Stair Ambulation

A four step staircase of standard step height and depth was used for completion of the stair walking activities (dimensions in Appendix 3). A handrail was attached to the stairs for safety purposes, but subjects were instructed not to use the handrail during the trials. Participants were able to practise walking on the stairs as necessary prior to the collection of data.

The subjects were required to ascend the stairs at a self-selected velocity, and then stand still and relaxed when they reached the top step. No further instruction was given. The same procedure was followed during the stair descent trials, with the subjects remaining stationary when they reached the bottom step (floor). Each trial provided two complete step cycles for both right and left leg. Four successful trials of both stair ascent and stair descent

were obtained from each subject, allowing a total of eight steps per activity for averaging.

4.3.4 Standing / Sitting

Subjects were seated on a standard chair, without arms, which had a seat height of 450mm from the floor. Subjects were asked to stand up from their seated position, and were required to remain standing still and relaxed for a period of approximately five seconds. Following this time, subjects were asked to return to their seated position on the chair. The participants were directed to complete the activity in a natural manner, and no further instruction regarding this activity was given.

Five successful trials were acquired from each subject. From this data, an average standing pattern and average sitting pattern for the individual subject was able to be obtained.

4.4 STATISTICAL DESIGN

A three-way analysis of variance was performed on an SPSS computer package to determine statistical significance of the obtained results. The three levels of the ANOVA were *group* (transtibial amputee or able-bodied), *side* (dominant or non-dominant limb) and *activity* (walk, stair ascent, stair descent, stand, sit). The significance level was set at 0.05. Both peak EMG and integrated EMG were analysed, on quadriceps and hamstrings muscle groups. Skewed data, obtained for quadriceps IEMG and all hamstrings values, was transformed using a logarithmic design. Following transformation, all values were near normally distributed and the ANOVA was completed on this transformed data. Post hoc testing was performed using Tukey's HSD to determine the location of differences when the ANOVA revealed significance.

CHAPTER 5: RESULTS

5.1 QUADRICEPS: PEAK EMG

The mean quadriceps peak EMG for all subjects during the five tasks is displayed in Figure 5.1.

When averaged across all activities, the TTA group demonstrated significantly lower peak EMG amplitude of the amputated limb quadriceps in comparison to the sound limb ($F(1,18) = 8.51, p=0.009$). The AB group displayed very little difference in peak quadriceps EMG between dominant and non-dominant limbs while completing the same tasks. Of the five tasks investigated, stair ascent and sit-to-stand (rising) resulted in significantly greater levels of peak EMG than the other activities of level walking, stair descent and sitting ($F(4,72) = 36.07, p<0.001$).

During level walking the able-bodied group displayed peak EMG levels of similar magnitudes on both dominant and non-dominant limbs. Symmetry between limbs is also noted in the TTA group during level walking. The TTA group displayed greater individual variations between limbs during level walking than the AB group (Appendix 4.1). Seven of ten TTA subjects recorded greater values of peak EMG on the sound limb. However the remaining three subjects displayed greatly increased levels of EMG activity on the amputated limb, resulting in a slightly skewed representation of the average peak value.

Stair ascent produced similar peak values in both limbs of the AB group, which was greater than that required for level ambulation. The sound limb of the TTA group demonstrated peak EMG levels similar to that of both limbs in the AB group. The peak EMG of the amputated limb quadriceps was reduced substantially during this activity, although this was not statistically significant.

During stair descent, the total peak EMG values of the quadriceps muscles were not significantly different to those recorded in level walking. In addition to this, neither of the groups displayed any significant differences in muscle activation between limbs during this activity. When considered individually, however, it is apparent that the sound limb generally had greater peak EMG values than the amputated limb during stair descent (Appendix 4.3). One TTA subject had a greatly increased amplitude of EMG activity on the amputated limb which influenced the overall average peak value, causing this average value to appear more symmetrical than would be expected. Variations are also evident in the AB group between the non-dominant and dominant limbs, but the majority of these subjects displayed peak EMG symmetry.

In the action of rising from a seated position, or sit-to-stand, the peak VL muscle activity is greater than during level walking, stair descent and sitting. In the AB group, dominant and non-dominant limbs demonstrated similar, or symmetrical, values of peak quadriceps EMG. The discrepancy between limbs in the TTA group during rising is evident ($F(4,72) = 9.36, p < 0.001$). The

sound limb of the TTA group displayed similar, but slightly greater, peak values to those of the AB group. The amputated limb quadriceps muscle was only activated to an amplitude of approximately half the peak EMG value of the sound limb.

During the activity of sitting to a chair, or stand-to-sit, the trends in peak EMG resemble those of the previously described activity of rising. AB group symmetry is also demonstrated during this task. The peak quadriceps EMG of the sound limb in the TTA group is comparable to that of both limbs in the AB group. The amputated limb VL muscle, however, is activated to a very low amplitude, being less than half the EMG magnitude of the sound limb. Although Tukey's post hoc test was too conservative to find a significant difference, a paired two-tailed *t*-test was performed on the amputated and sound limb values. This test indicated the difference between limbs in this activity to be highly significant ($t = 6.186$, $p = 0.0002$).

QUADRICEPS: PEAK EMG

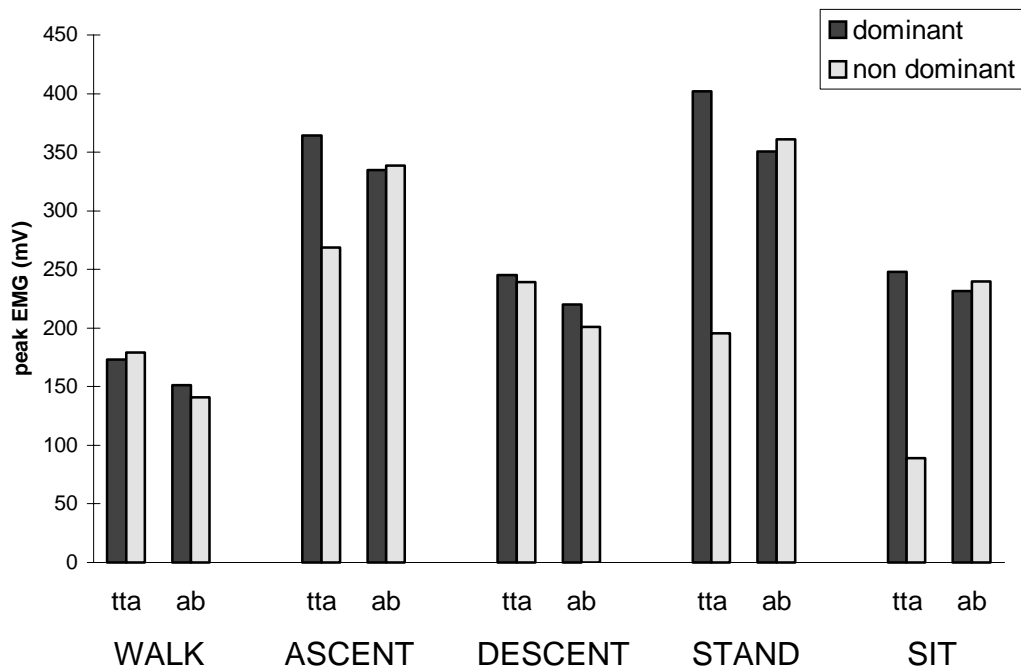


Figure 5.1. Peak EMG of quadriceps muscles; mean of all subjects during each activity.

A significant 3-way interaction effect is present between limbs of TTA subjects during the STAND and SIT activities ($p < 0.001$).

TTA: transtibial amputee; AB: able-bodied subject.

5.2 QUADRICEPS: INTEGRATED EMG

The mean quadriceps integrated EMG for all subjects during the five tasks is displayed in Figure 5.2.

The trends of the integrated EMG (IEMG) results are similar to those of the peak EMG results previously detailed. However, unlike the peak EMG results, the differences between sound and amputated limbs were not found to be statistically significant across all activities. For all activities the AB group displayed symmetry of IEMG between limbs. Some individual variations can be seen (Appendices 4.6-4.10), but the dominant and non-dominant limbs generally display similar integrated EMG values.

The task of level ambulation resulted in significantly less IEMG than all other activities investigated ($F(4,72) = 68.38, p < 0.001$). Although some variability is evident between subjects (Appendix 4.6), both AB and TTA groups displayed IEMG symmetry between dominant and non-dominant limbs. The area values for the TTA group are greater than those displayed by the AB group.

When completing the stair ascent activity, the AB group demonstrated symmetrical muscle activation between dominant and non-dominant limbs. Although some differences existed between sound and amputated limbs of

the TTA group (Appendix 4.7), this average difference between limbs was small and insignificant. Stair descent resulted in no significant differences between limbs in either AB or TTA group.

The task of rising resulted in significantly greater muscular activation than most other activities performed including level walking, stair descent and sitting ($F(4,72) = 68.38, p < 0.001$). During this activity of sit-to-stand significantly less IEMG was recorded on the amputated limb than the sound limb ($F(4,72) = 16.07, p < 0.001$). The sound limb IEMG was also substantially greater than both dominant and non-dominant limbs of the AB group.

During the activity of stand-to-sit, a significant difference was also observed between sound and amputated limbs in the TTA group ($F(4,72) = 16.07, p < 0.001$). As described previously in the action of rising, the quadriceps IEMG of the sound limb was greater than that recorded on both dominant and non-dominant limbs of the AB group. The amputated limb displayed considerably lower IEMG values than the AB group, which once again demonstrated symmetry of quadriceps activation.

QUADRICEPS: INTEGRATED EMG

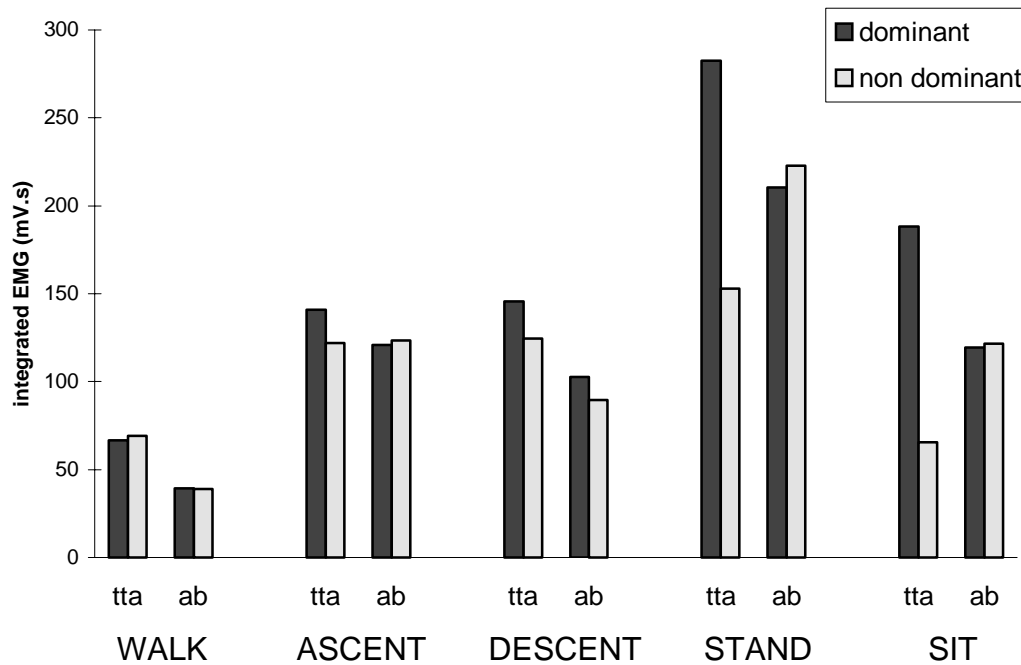


Figure 5.2. Integrated EMG of quadriceps muscles; mean of all subjects during each activity.

A significant 3-way interaction effect is present between limbs of TTA subjects during the STAND and SIT activities ($p < 0.001$).

TTA: transfemoral amputee; AB: able-bodied subject.

5.3 HAMSTRINGS: PEAK EMG

The mean hamstrings peak EMG for all subjects during the five tasks is displayed in Figure 5.3.

During all activities the hamstrings muscles were found to display much greater variability than the quadriceps muscles (Appendices 4.11-4.15). Although this result was noted in both groups, the TTA group displayed even greater variability than the AB group. The average peak value of hamstrings activity is not a clear representation of this muscle activation during each task due to the large amount of variability observed (both between and within individuals). This finding is most evident in the ambulatory activities of level walking, stair ascent and stair descent. The comparison of peak EMG activity in the sound and amputated limbs of the TTA group was not significantly different to the comparison of dominant and non-dominant limbs in the AB group.

The task of stair ascent resulted in the greatest peak activation of the hamstrings muscles, being significantly higher than during stair descent and the stand and sit activities ($F(4,72) = 47.14, p < 0.001$). The activity of stand-to-sit resulted in significantly lower hamstrings peak EMG than all other tasks investigated ($F(4,72) = 47.14, p < 0.001$).

It is evident that the hamstrings muscles during the sit-to-stand and stand-to-sit activities displayed similar trends to those of the quadriceps muscle during the same activities. The sound limb of the TTA group demonstrated greater peak EMG than the amputated limb in both tasks, although no significant results were achieved.

HAMSTRINGS: PEAK EMG

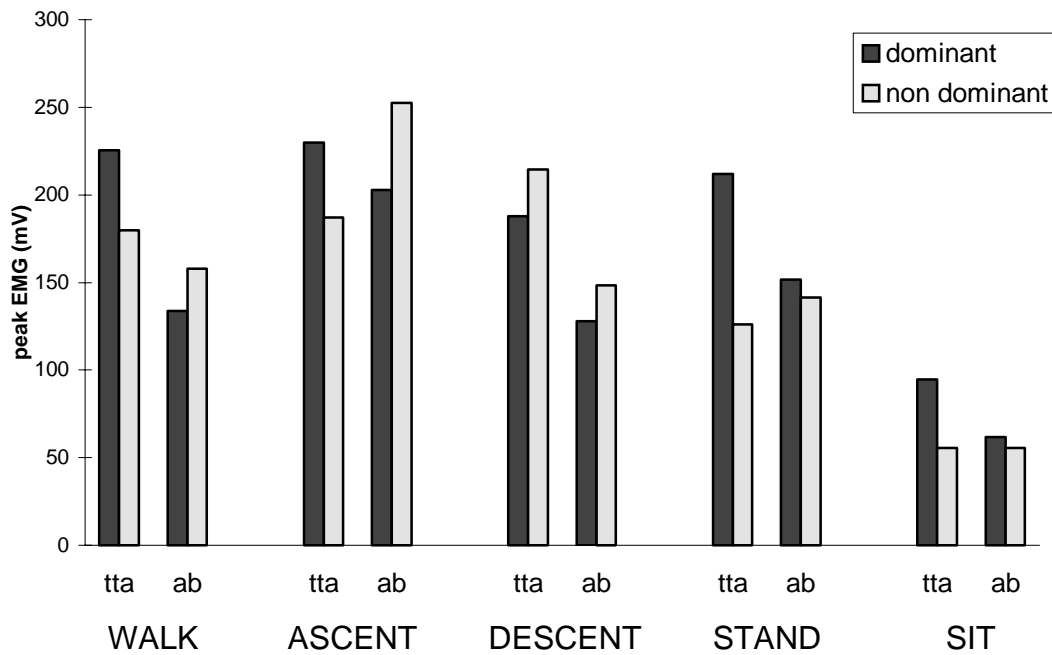


Figure 5.3. Peak EMG of hamstrings muscles; mean of all subjects during each activity.

TTA: transtibial amputee; AB: able-bodied subject.

5.4 HAMSTRINGS: INTEGRATED EMG

The mean hamstrings integrated EMG for all subjects during the five tasks is displayed in Figure 5.4.

The variability displayed in the peak amplitude EMG is also evident in the integrated EMG results (Appendices 4.16-4.20). The activity of stand-to-sit resulted in significantly lower hamstrings IEMG than all other activities performed ($F(4,72) = 37.23, p < 0.001$). Level walking also displayed significantly less muscle activity than stair ascent, descent and rising ($F(4,72) = 37.23, p < 0.001$).

Hamstrings IEMG results demonstrated similar trends to the quadriceps IEMG results during the stand and sit activities. In the TTA group, the sound limb displayed significantly greater hamstrings muscle activity than the amputated limb during the activity of rising, or sit-to-stand ($F(4,72) = 3.43, p = 0.013$). This sound limb IEMG magnitude was also considerably greater than that required on either limb of the AB group.

HAMSTRINGS: INTEGRATED EMG

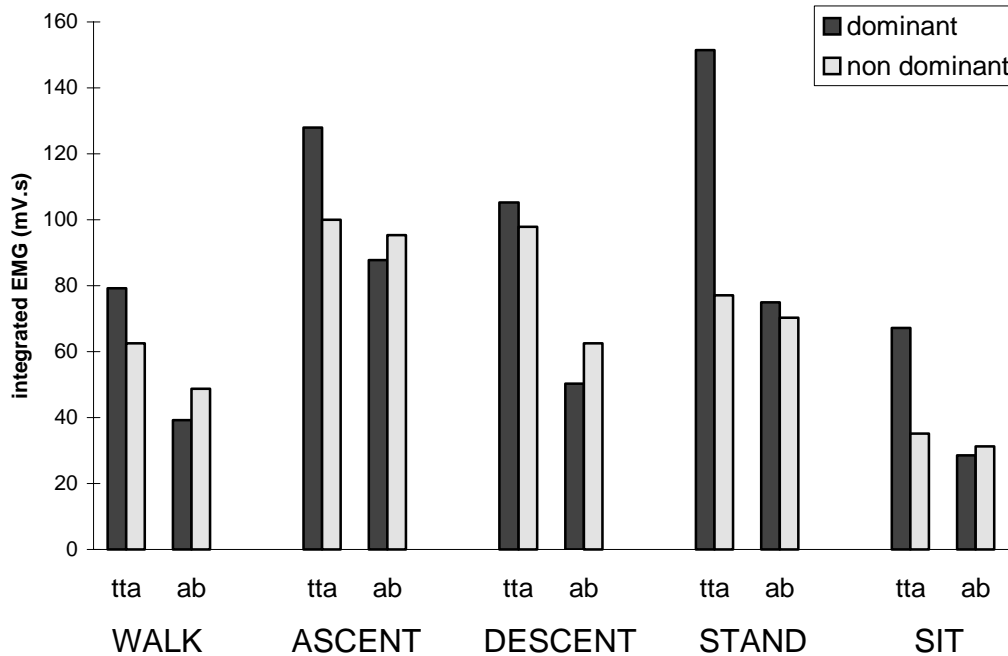


Figure 5.4. Integrated EMG of hamstrings muscles; mean of all subjects during each activity.

A significant 3-way interaction effect is present between limbs of TTA subjects during the STAND activity ($p=0.013$).

TTA: transfemoral amputee; AB: able-bodied subject.

5.5 EMG PROFILES

The mean EMG profiles of the TTA subjects and AB subjects during level walking, stair ascent and stair descent are displayed in Figures 5.5 - 5.10. (An example of individual subject EMG profiles of sound and amputated limbs (TTA subject no. 1) is included in Appendix 5).

The TTA group generally displayed more variable EMG profiles than those of the AB group for all activities. The sound limb of the TTA group often displayed similar patterns and peak activation as both dominant and non-dominant limbs of the AB group. It was noted that the amputated limb demonstrated less consistent patterns, with differences occurring in timing of peak EMG activity and amplitude of this peak.

During level walking, prolonged quadriceps activity was noted on both amputated and sound limbs. Some degree of co-contraction between quadriceps and hamstrings muscles was evident during level and stair ambulation in the amputated limb.

LEVEL WALKING: EMG profiles for quadriceps (VL) and hamstrings (BF)

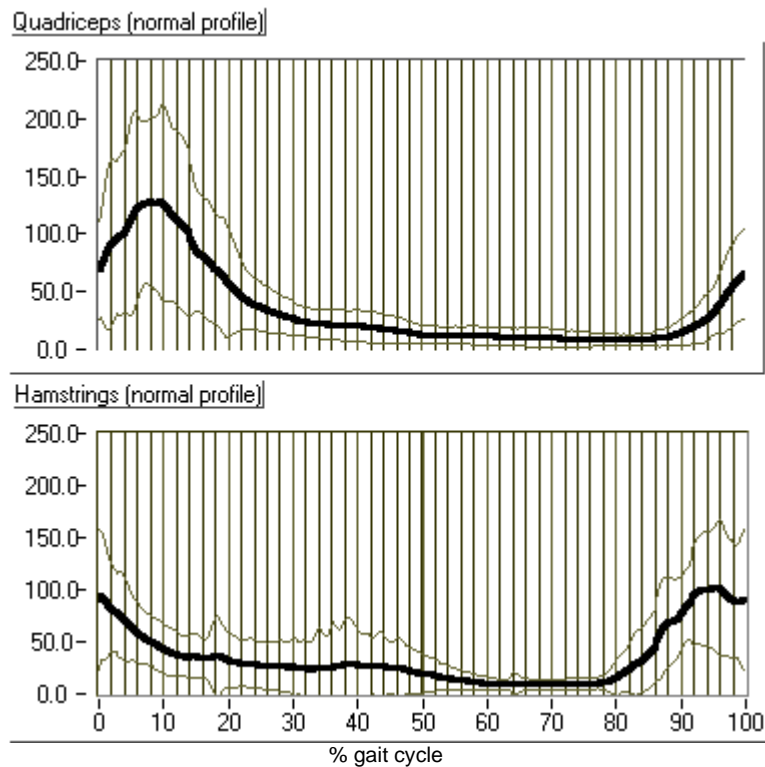


Figure 5.5. EMG profiles (in mV) for quadriceps and hamstrings during level walking. Mean \pm standard deviation of Able-Bodied subjects (n=10).

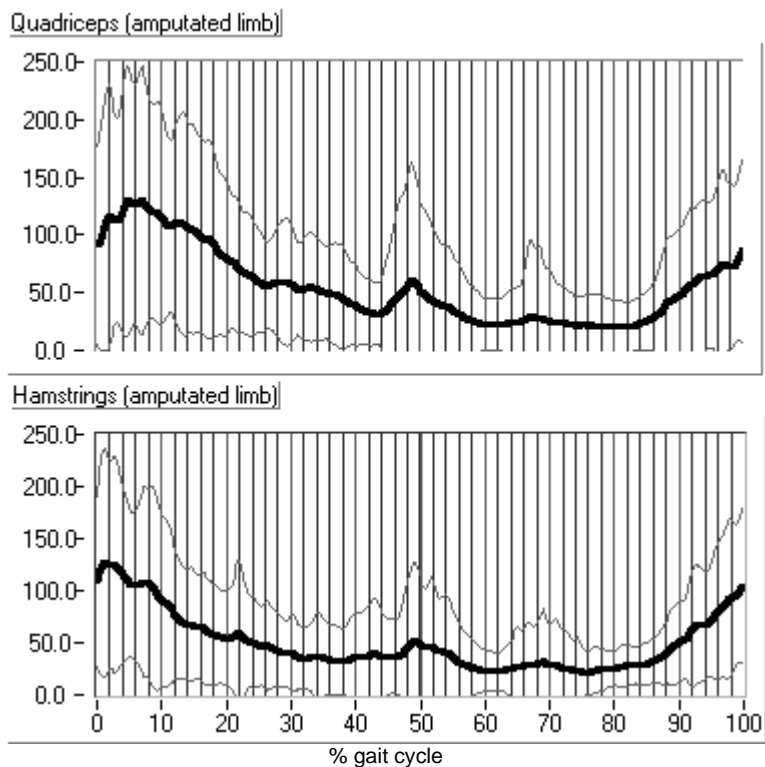


Figure 5.6. EMG profiles (in mV) for quadriceps and hamstrings during level walking. Mean \pm standard deviation of Transtibial Amputee subjects (n=10).

STAIR ASCENT: EMG profiles for quadriceps (VL) and hamstrings (BF)

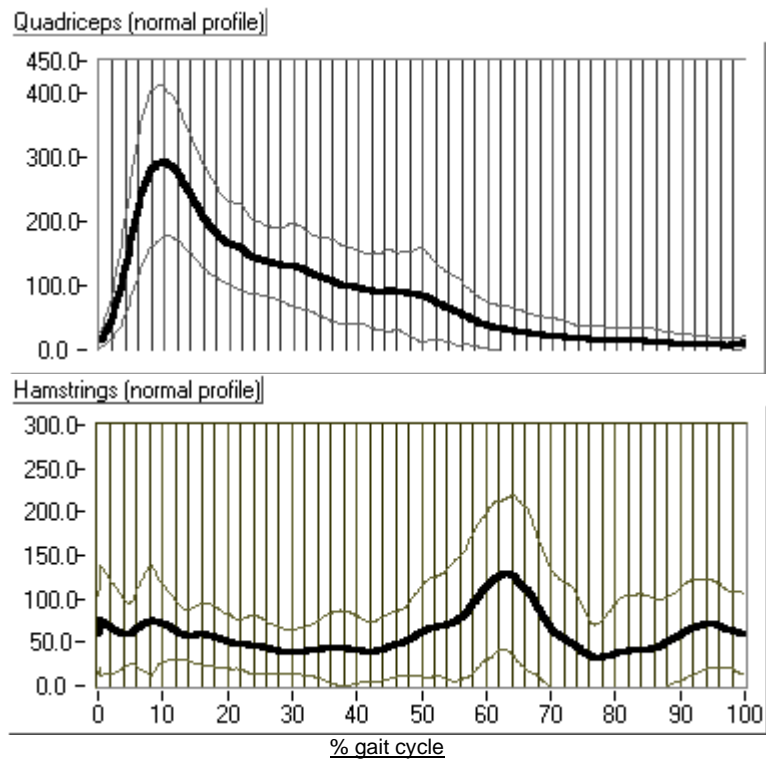


Figure 5.7. EMG profiles (in mV) for quadriceps and hamstrings during stair ascent. Mean \pm standard deviation of Able-Bodied subjects (n=10).

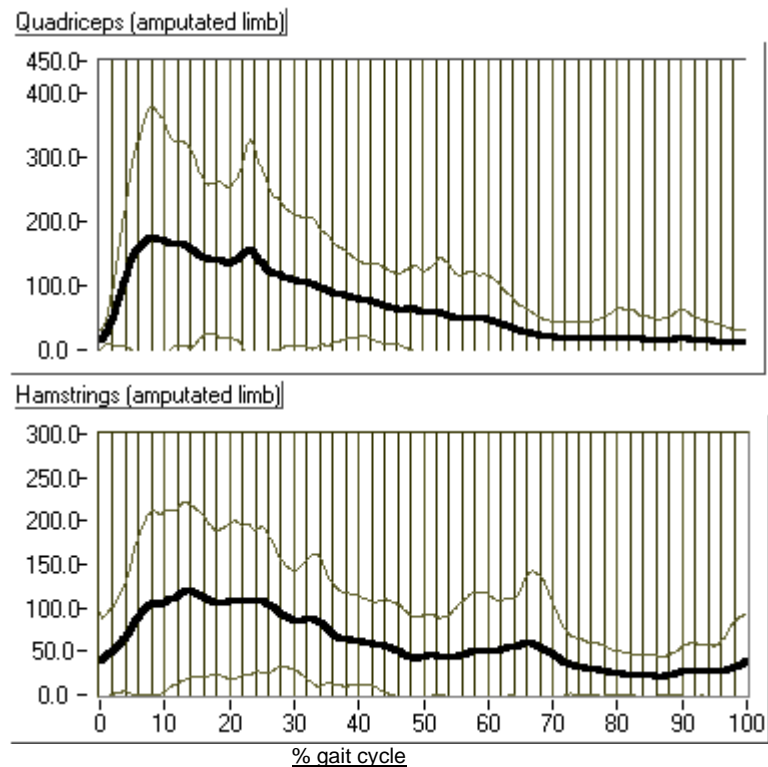


Figure 5.8. EMG profiles (in mV) for quadriceps and hamstrings during stair ascent. Mean \pm standard deviation of Transtibial Amputee subjects (n=10).

STAIR DESCENT: EMG profiles for quadriceps (VL) and hamstrings (BF)

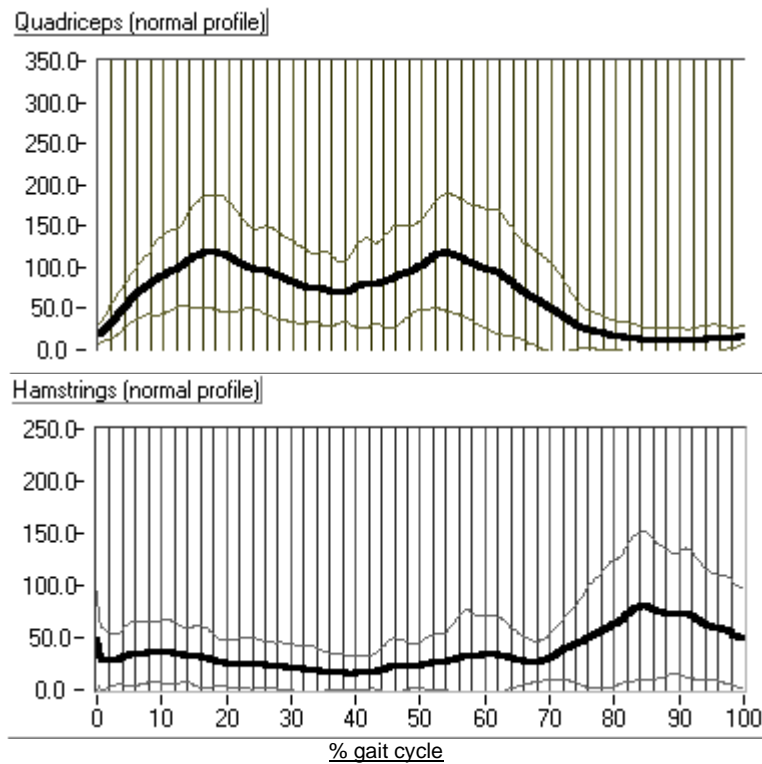


Figure 5.9. EMG profiles (in mV) for quadriceps and hamstrings during stair descent. Mean \pm standard deviation of Able-Bodied subjects (n=10).

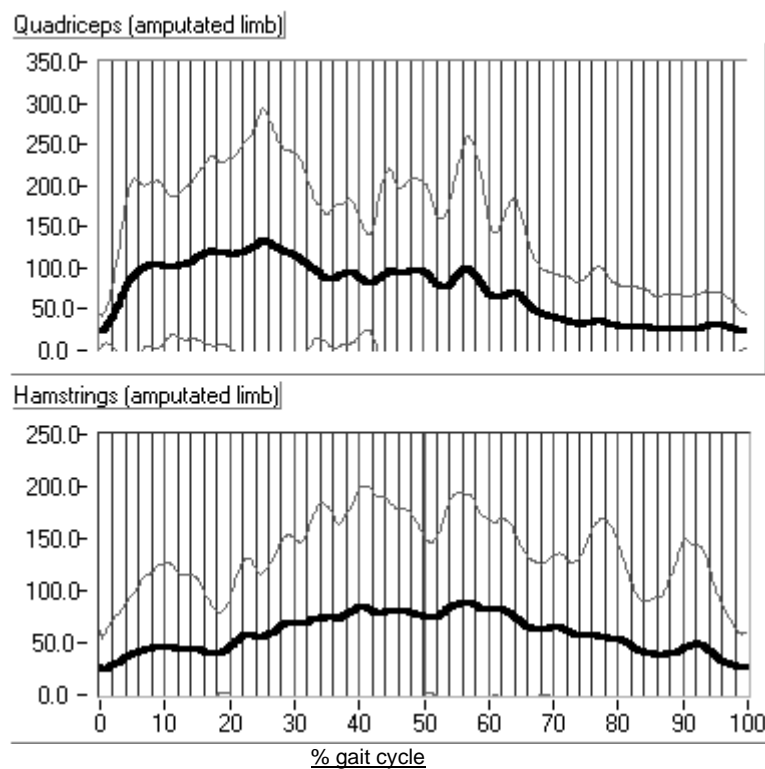


Figure 5.10. EMG profiles (in mV) for quadriceps and hamstrings during stair descent. Mean \pm standard deviation of Transtibial Amputee subjects (n=10).

CHAPTER 6: DISCUSSION

6.1 OVERVIEW OF RESULTS

As hypothesised, the transtibial amputee group demonstrated symmetry of peak and integrated quadriceps EMG during the activity of level walking. These results were also closely associated with the values of the able-bodied group during the same activity. The EMG profiles of the TTA group displayed certain variations from those of the AB group. These differences demonstrate the compensatory mechanisms occurring in the lower limbs of the TTA subjects during gait.

During stair ambulation the difference between limbs in the TTA group was expected to be greater than the difference naturally occurring between limbs in the AB group. Although variability was evident in the TTA group, this difference in EMG between the sound and amputated limbs was not found to be statistically significant. Variations in amputated limb EMG profile and timing of peak EMG were evident, and appear to be related to limitations of the transtibial prosthesis during the gait cycle.

The greatest differences in EMG between the sound and amputated limbs were observed in the stand and sit activities. These results confirm the initial hypotheses. During these tasks the amputated limb quadriceps and hamstrings muscles were substantially reduced in comparison to the sound limb. This sound limb dominance may be a contributing factor to the disuse atrophy commonly observed in the amputated limb thigh muscles. The differences in muscle activation during these activities may also be attributed to limitations of the prosthesis.

6.2 STAND AND SIT ACTIVITIES

The results of this investigation indicate that the amputated limb is activated to a lesser degree than the sound limb during many of the specified tasks. The activity in which this sound limb dominance was most evident is that of rising from a seated position. Although this activity in the AB group demonstrated significantly greater levels of muscle activation than other activities investigated, including level ambulation and stair descent, the amputated limb had greatly decreased muscle usage during the activity.

In the AB subject the action of rising begins with the knees flexed to 90 degrees or greater. This position ensures the body's base of support is close to the seat, allowing an efficient transfer of body weight over the subject's feet during rising. The activity is predominantly due to the action of the quadriceps muscles which develop the tension required to extend the knees, and bring the body's centre of mass over the base of support. This procedure of muscle contraction, performed a number of times over a day, may be one of the activities which is involved in the prevention of muscle atrophy due to disuse. Schüldt et al (1983) has previously reported that this action of rising from a seated position can increase strength for the quadriceps muscles, particularly at larger knee angles.

In the amputated limb, reduced quadriceps activation was evident in all TTA subjects. This may be due to habit, as the amputee initially learns to transfer

most body weight to the sound limb during the action of rising, in order to alleviate any pain or discomfort in the residual limb. This is achieved by positioning the prosthetic limb at an angle in front of the sound limb (at less than 90 degrees of knee flexion), which allows more weight to be transferred to the sound limb, and also increases the stability due to a wider base of support once standing. This action has also been reported by Petschnig, Baron, Kotz, Ritschl and Engel (1995), who found an increased strength in the non-operated limb. If the amputated limb is unable to reach a position of knee flexion greater than 90 degrees, due to limitations of the prosthetic socket, the same result of reduced amputated limb muscle stimulation will ensue.

The quadriceps muscles require a high level of force during the action of rising. In the amputee, the decreased lever arm of the tibial remnant may affect the ability to produce the level of force required. Alternatively, increased quadriceps forces tending to extend the knee may result in pain at the anterodistal tibia due to increased pressure against the prosthetic socket. In this situation, the amputee would be likely to adopt the pattern of weight transfer to the sound limb during rising in order to alleviate or prevent the occurrence of this pain.

The stand-to-sit activity displayed similar results to the sit-to-stand activity detailed above. This task also demonstrated a sound limb dominance of the quadriceps muscles, although the peak muscle activity was not found to be significantly greater than that of level walking. This would be expected as the

task is due to lengthening of the quadriceps and therefore an eccentric action of these muscles. The EMG amplitude recorded during eccentric work is less than that of equal concentric work (Komi, 1973), so although the muscular tension of this activity may be similar to that during rising, a lower peak EMG is displayed.

The present investigation demonstrated that peak hamstrings activity during rising and sitting is not significantly greater than most other activities investigated. The action of hamstrings, being a flexor of the knee and extensor at the hip, is not in an optimal position to be of assistance in the stand-to-sit activity. Schüldt et al (1983) also reported that the hamstrings muscles are activated only to a low level during rising. The sound limb of the TTA group however demonstrated increased hamstrings activation during these tasks, indicating a pattern of coactivation between quadriceps and hamstrings muscles. This hamstrings co-contraction may provide additional stability due to the greater demand of body weight support in the sound limb of the TTA subjects.

The integrated EMG results (figures 5.2 and 5.4) displayed greatly increased magnitudes of quadriceps and hamstrings muscle activation in the sound limb compared to the AB subjects. This result may be attributed to a longer time required for the amputee to complete the activity.

6.3 LEVEL WALKING

During the activity of level walking, both groups displayed symmetry of quadriceps muscle activation. The peak and integrated EMG of both sound and amputated limbs in the TTA group appeared to be greater than those of the AB group. These differences in values may be due to inter-subject variations within the groups. A previous investigation of transtibial amputees during gait has reported greatly increased magnitudes of EMG activity between amputee and able-bodied subjects (Winter and Sienko, 1988). However, this study recorded EMG, unilaterally, on only three TTA subjects, and reported results for one of these subjects. The claims made in the investigation were not supported by statistical analysis. Differences in muscle activation to this extent were not evident in the current investigation.

Examination of individual patterns reveals that the TTA group displayed greater variability of EMG activity during the gait cycle. A typical EMG profile for the VL muscle was displayed by all limbs. The peak quadriceps activity occurred at the beginning of the stance phase to control knee flexion by eccentric action. Following this peak, the quadriceps muscle activity of the AB group reduced to a minimum. In the TTA group this activity decreased noticeably, with most amputee subjects displaying a prolonged low amplitude of quadriceps EMG activity on both amputated and sound limbs. This prolonged activity may explain the greater magnitudes of IEMG results in the TTA group as compared to the AB group.

The prolonged quadriceps activity assists in stabilising the knee joint during stance phase, as a loss of plantarflexor action may result in instability of the amputated limb at this time (Culham et al, 1986; Breakey, 1976). The VL profile of the amputated limb in certain TTA subjects displayed an additional peak of activity just prior to toe off. At this point in the gait cycle, increased hip flexion may be required to pull the limb forward, due to the lack of push-off action normally generated by the plantarflexor musculature. Activation of VL may serve to control the resulting heel rise. It has also been suggested that prolonged quadriceps activity is required to counteract hamstrings activity on the amputated limb (Winter and Sienko, 1988), but this finding of hyperactive hamstrings muscles was not supported in the present study.

Sound limb hamstrings were seen to display similar profiles of EMG activity to both dominant and non-dominant limbs in the AB group. The peak hamstrings activity occurred at the end of the gait cycle, where it is acting to decelerate the lower limb at terminal swing phase. Following heel contact, the hamstrings act to resist the flexion tendency by stabilising the hip. This activity decreases as the body progresses over the foot, and is minimal during early swing. Conversely, the amputated limb displayed the peak of muscle activity at the beginning of stance phase. This peak occurs simultaneously with the VL muscle, implying co-contraction of the quadriceps and hamstrings muscles during early stance. This result essentially agrees with a number of previous authors who have reported this pattern of coactivation during transtibial amputee gait (Culham et al, 1986; Winter and Sienko, 1988). Coactivation has been reported to compensate for lost ankle plantarflexor activity and provide increased stability of the amputated limb.

6.4 STAIR AMBULATION

It was expected that stair ambulation would result in a reduced amputated limb activation in comparison to the sound limb, particularly due to the high levels of peak quadriceps activity required during stair ascent. Considered individually, many of the TTA subjects demonstrated sound limb dominance (Appendices 4.2-4.3), although these values were disguised in the averaged results and were not found to be statistically significant.

Previous investigations of stair walking in able-bodied individuals have reported that stance phase is greatly increased as a percentage of the gait cycle than during level walking (McFadyen and Winter, 1988). Powers et al (1996) and Torburn et al (1994) have also demonstrated that the transtibial amputee spends significantly more time on the sound limb than the amputated limb during stair ambulation. This would be expected to result in an increased IEMG of the sound limb thigh musculature, but was not evident in the present investigation.

Although the plantarflexors are active in both modes of stair ambulation, it has been suggested that this is not a main source of forward progression in stair walking (McFadyen and Winter, 1988). Thus it does not appear that the loss of the plantarflexor musculature affects stair ambulation in the same way as level walking, where plantarflexors provide the greatest forward progression.

Powers et al (1996) found that the reduced ankle motion of the prosthesis was the main factor causing the gait deviations observed in stair walking, as the range of motion required is greater than that during level ambulation (Andriacchi et al, 1980). This limited ankle motion resulted in instability and subsequent postural compensations, such as increased hip flexion and pelvic tilt, to advance the body's centre of mass over the prosthetic foot. In order to achieve these compensatory mechanisms, more intense and prolonged EMG activity of the amputated limb musculature (as a percentage of MVC) was reported by Powers et al (1996). This result was contradictory to present findings.

Observation of the EMG pattern for the stair ascent gait cycle demonstrated a similar pattern of activity for the sound limb and both limbs of the AB group. During stair ascent, the main progression from one step to the next is provided by knee extensor activity, which occurs at the beginning of stance phase and continues until toe off. The amputated limb displayed a reduced magnitude of this peak EMG activity. This may be due to compensatory motions such as forward trunk lean (Powers et al, 1986), resulting in a lower quadriceps activation requirement for propulsion. The plantarflexor muscles of the sound limb may also provide extra push-off activity to assist in forward progression during stair ascent. The remainder of the gait cycle of the amputated limb displayed similar magnitudes and phasing as the sound and AB limbs.

Although the hamstrings results were more varied than the quadriceps during stair ascent, the peak BF generally occurred at a consistent time in the gait cycle for both limbs in the AB group. This peak of hamstrings activity occurred during toe-off and early swing to provide knee flexion and progress the swinging limb to the next step. However, in the TTA group the hamstrings activity was more variable for both sound and amputated limbs. Peak hamstrings activity of the amputated limb occurred at the beginning of the stance phase of stair ascent, once again indicating a pattern of co-contraction with the quadriceps muscles.

The EMG profile of the VL muscle during stair descent displayed a typical profile of two muscle activity peaks occurring during stance phase. The first occurred at foot contact on the step below, when VL is acting to provide energy absorption and control of the knee. Progression from one step to the next during stair descent is provided by a second eccentric contraction of the quadriceps in a *controlled lowering* phase (McFadyen and Winter, 1988). This typical profile was displayed by both dominant and non-dominant limbs of the AB group, and was similar to the sound limb of the TTA group. Conversely, the amputated limb demonstrated reduced muscle activation during this second peak, or lowering phase. Torburn et al (1994) reported that TTA subjects were unable to achieve a smooth step down due to inadequate dorsiflexion of the prosthetic ankle. To compensate for this limited ankle motion, the amputated limb stance phase is reduced, and the body weight is transferred quickly to the next step, at the prosthetic toe-off

stage in the gait cycle. This has resulted in a decreased lowering phase, and consequently less quadriceps activation.

In the AB group a peak of hamstrings activity occurred at the end of the swing phase. This was due to the eccentric action of BF, providing deceleration at the knee for the swinging or extending leg. The TTA subjects demonstrated a less consistent profile of hamstrings activity, as well as variability in the timing of the peak EMG. Continual activation of the BF muscle was commonly observed throughout the stair descent cycle. This finding was also noted by Powers et al (1996), who suggested that it may be a protective response in order to prevent excessive pressure of the anterodistal tibia against the prosthetic socket.

6.5 RELATIONSHIP TO MUSCLE ATROPHY

The molecular mechanisms responsible for changes in muscle with different types of activity remain unclear, but appear to be related to the frequency and intensity of the contractile activity in the muscle fibres (Vander et al, 1986). Regular stimulation of these muscle fibres is involved in the preservation of normal strength.

In able-bodied individuals daily tension levels of specific muscles are sufficient to maintain the force capacity of these muscles at a constant level (Häkkinen, 1994). The regular muscular tension may be lower than normal when a decline in daily physical activity, or intensity of these activities, takes place. The cessation of a regular pattern of muscle activation leads to atrophy and a decrease in force capacity of the involved muscles. A lack of sufficient muscle stimulus may result in a progressive decrease in strength.

The transtibial amputee subjects investigated in the present study displayed sound limb dominance in many of the tasks undertaken. This dominance results in a reduction of thigh muscle activation in the amputated limb, during activities which may be involved in the maintenance of normal strength. Reduced stimulation of individual muscle fibres occurs during these tasks, and the tension developed in the quadriceps and hamstrings muscle groups is greatly decreased. The level of amputated limb thigh muscle activation may be inadequate to prevent the occurrence of muscle atrophy due to disuse.

This situation was most evident during the activities of rising and sitting. A reduction in amputated limb thigh muscle activity during these tasks was demonstrated by all transtibial amputee subjects. It is likely that additional common daily activities occur in which this sound limb dominance is displayed, further contributing to the disuse atrophy.

The reduction in activation of the amputated limb thigh muscles may be due to the decreased lever arm of the tibial remnant, which affects the ability of the quadriceps to produce high forces during the activities investigated. However, if the limiting factor of these activities is due to prosthesis design, the results suggest that there are two main considerations in the transtibial prosthesis.

The replacement of the ankle mechanism has previously been reported as a cause of altered thigh muscle activity in the transtibial amputee (Breakey, 1976; Culham et al, 1986; Winter and Sienko, 1988). During level walking the loss of the plantarflexor musculature results in compensatory gait strategies, but the peak thigh muscle activity in the current study was found to be symmetrical between sound and amputated limbs, and similar to that of AB subjects. During stair ambulation the postural compensations were due to the decreased ankle range of motion in the prosthesis. Although variations occurred in EMG profiles, the thigh muscle activation in the amputated limb was not significantly different to that occurring in the sound limb.

The greatest discrepancy between sound and amputated limbs occurred during the tasks of rising and sitting. As previously discussed, socket design may be the limiting factor in these activities, resulting in sound limb dominance, and a reduction in activation of the amputated limb. This is due to the inability to flex the knee past 90 degrees, or to pain at the anterodistal tibia due to pressure on the socket.

The results demonstrate that the prosthetic socket is an important consideration in the transtibial prosthesis. Limitations of the socket design result in inadequate contraction of the amputated limb quadriceps muscles, during activities which may be involved in the prevention of muscle atrophy. Although gait is an important functional requirement for the transtibial amputee, other common daily activities should also be considered during prosthesis design and manufacture.

6.6 EMG AS AN INDICATOR OF MUSCLE ACTIVITY

The EMG signal has been reported to be the single best representation of the neurological control of skeletal muscle (Winter, 1988). The linear envelope representative of this EMG signal, as used in the present study, has been found to closely follow the rises and falls of muscle tension (Winter, 1990). The peak muscle tension developed during loading appears to be related to muscle hypertrophy, although the exact stimulus for this muscle hypertrophy, or the prevention of muscle atrophy, is presently unclear. EMG was used as a reliable indicator of the amount of activation which occurred in the thigh muscles during the specified activities. During this investigation, both the peak activity and the area under the EMG curve (integrated EMG) were measured. From the results achieved it is evident that these measurements display similar trends, and are therefore closely related in their representation of muscle activity during a given task.

Electromyography measured by surface electrodes is a valid signal to represent the average motor unit activity of superficial muscles. The risk of recording signals from adjacent muscles (crosstalk) is limited if the muscle being recorded is large, such as the quadriceps femoris or hamstrings muscles investigated in the present study (Winter, 1990).

During each activity, the EMG pattern for a given muscle, within the individual subject, appeared to be highly repeatable. This is in agreement with

Arsenault, Winter and Marteniuk (1986a), who found that a reliable pattern of muscle function exists for a given subject. The average EMG profile for each subject was then an accurate representation of the muscle activity occurring during the task. The EMG profiles between limbs of the individual subject appeared to be comparable, due to equipment design and careful electrode preparation and placement. This intra-subject comparison was used to test muscle activity between limbs in both groups.

The observed differences between subjects (inter-subject variability) may be due to such factors as subcutaneous tissue, skin temperature, muscle mass and recruitment profiles (Winter, 1984). Differences relating to age were controlled by attempting to age match the subject groups. Although the EMG signal is sensitive to changes in velocity, it was anticipated that a self-selected, comfortable cadence would limit the effect of this variable on subjects with a similar fitness or activity level. It is assumed that biological or electrode factors which result in differences between individuals are randomly distributed across the individuals in the different groups. Therefore comparisons between *groups* of individuals appear to be a valid measure.

Normalising the gait cycle, or length of time taken for each activity, to 100 percent is a feasible and acceptable method of obtaining an average EMG inter-subject profile for each group (Arsenault et al, 1986a). Although individual differences may be disguised in this process, the pooled data represents a generalisation, or simplification, of the role of this muscle during the specified activity.

Several previous investigations of EMG profiles during gait have reported EMG amplitude results as a percentage of the maximum voluntary contraction (MVC). This technique can result in greater variability in inter-subject averages (Winter, 1988). The use of an isometric contraction to standardise a dynamic muscular action, such as that occurring in gait, has also been questioned (Schüldt et al, 1983; Lyons et al, 1983). Westing, Cresswell and Thorstensson (1991) reported that maximum contraction may not be an accurate representation of the strength of a muscle. The neural drive to the agonist could be reduced in conditions of extreme muscular tension, even during maximum voluntary effort. This inhibition acts in order to protect the musculoskeletal system from injury by maintaining muscle tension within safe limits. Inhibition may be especially prevalent following trauma to the limb. For the above reasons, EMG measurements in the current investigation were not standardised to a maximum contraction.

6.7 LIMITATIONS OF THE STUDY

In the current investigation, EMG activity was the only parameter measured. It would be beneficial to record kinematic and/or kinetic data in order to more accurately interpret the obtained results. The compensatory mechanisms in the present study were estimated, or obtained from previous literature. Slow motion video analysis could also assist in analysis of the EMG results.

The stair walking trials were recorded on a four step staircase. The subjects did not develop a constant walking pattern during this activity. The profile of EMG activity would be expected to become more consistent on a full flight of stairs. This has also been noted as a limitation in previous stair walking investigations (Andriacchi et al, 1980; McFadyen and Winter, 1988).

In the present investigation the footswitches remained positioned under the heel during the stair ambulation activities. A series of closing footswitches placed under the great toe and first metatarsal head would be a more accurate method of obtaining a point of initial contact (zero percent of the gait cycle), than the subjective methods utilised in this study. This would be an important consideration in the analysis of the EMG profiles of the muscles. However, peak values obtained were not affected by this process. In order to achieve an accurate point of initial contact during the sit and stand activities, the subject could stand onto a force platform. This would also allow further analysis of the sit and stand data.

The assumption of thigh muscle atrophy and reduced strength in the amputated limb was made from previous literature. In order to obtain a measure of thigh muscle atrophy, circumferences were taken using a tape measure (Appendix 2). This is neither an accurate nor a reliable method, as subcutaneous tissue obscures the true muscle atrophy occurring. A method such as computed tomography would allow more precise indication of muscle wastage by utilising a cross sectional area of the thigh. In this way, the area of an individual muscle, or muscle group, may be obtained. Biopsy techniques may, however, be the only true indication of muscle fibre atrophy. In addition, thigh muscle strength was not quantitatively measured in the current study. This would also be a useful measure to obtain, as it may allow further analysis of the muscle activation patterns and postural compensations which occur in each subject.

6.8 FURTHER INVESTIGATION

In this investigation, the stand and sit activities resulted in the greatest reduction in amputated limb thigh muscle activation. Further research is required in this area, as no literature could be found to date on these activities in the transtibial amputee. Motion analysis, as well as further investigation of prosthetic limitations during rising and sitting, is warranted. Advances in this area may greatly benefit the transtibial amputee.

A number of suggestions for future investigation into quadriceps atrophy in the transtibial amputee may be indicated. The activities completed in the current study were performed in a gait laboratory, which may not be the optimal setting for investigating common daily activities. In order to research this subject further, it would be of benefit to record quadriceps muscle activity over an extended period of time or over a whole day. This is a feasible method of obtaining an indication of total quadriceps usage in common activities in the transtibial amputee, and allow further conclusions to be reached regarding disuse atrophy.

Further investigation is required into the relationship between EMG activity and muscle atrophy before more accurate and valid conclusions can be reached using this research technique. This area is not currently well documented in the literature.

It would also be of interest to observe if a correlation exists between the time since amputation and the amount of atrophy and/or EMG activity occurring in the thigh muscles. The time spent in post-surgical immobilisation would also be an important consideration in this topic. Repeated tests over a number of years would give some indication of whether disuse atrophy is progressive. Habitual gait patterns or movements could also be investigated in this way. A number of follow-up studies have been reported which cover the period of up to ten years following lower limb surgery, trauma and immobilisation (Arvidsson, Eriksson, Häggmark and Johnson, 1981; Rutherford, Jones and Round, 1990; Petschnig, Baron, Kotz, Ritschl and Engel, 1995).

Another area which deserves further attention is that of strength training in the transtibial amputee. Periera and Kafalas (1995) suggested that the amputee would benefit from gait training (following a programme of strength training) in order to functionally utilise the increased muscle strength available. In addition, disuse atrophy should be investigated following strength training of the amputated limb thigh muscles. The subject's performance immediately following strength training may be compared to performance after a period of detraining. A reduction in strength to the pretraining level after this period may be indicative of atrophy due to disuse. Strength training would not appear to be advantageous to the amputee in this situation. If the subject does not revert to the pretraining level, a programme of strength training would appear to be of benefit for the transtibial amputee.

Endurance training of the thigh muscles should also be investigated as atrophy appears to greatly affect the slow oxidative, or Type I, muscle fibres. The training of these Type I fibres may be more relevant to endurance activities such as walking. This would also result in a reduced rate of fatigue of the involved muscles.

CHAPTER 7: CONCLUSION

Thigh muscle atrophy commonly occurs in the transtibial amputee, and is associated with a decrease in strength. In able-bodied individuals, daily activities are sufficient to maintain muscle strength at a constant level. A reduction in intensity of these activities leads to muscle atrophy and a decrease of force capacity of the involved muscles. In the transtibial amputee, sound limb dominance results in a reduction in activation of the amputated limb thigh muscles.

Of the common daily tasks investigated in this study, the actions of rising and sitting provided the greatest evidence of reduced quadriceps activity in the amputated limb. These activities, performed a number of times over a day, are involved in the maintenance of normal strength in able-bodied individuals. The reduced activation of the amputated limb muscles during these activities results in a decreased muscle stimulation, and subsequent muscle atrophy. The sound limb dominance displayed by the transtibial amputee is likely to occur in additional common activities, further contributing to the disuse atrophy observed. Whether strength training of the amputated limb thigh muscles is beneficial to the transtibial amputee requires further investigation, as it is evident that daily activities are not sufficient to *maintain* the strength of these muscles.

Since the greatest reduction in amputated limb thigh muscle activation occurs during the activities of rising and sitting, it is important that daily activities, other than gait, are considered during prosthesis design. The results of this investigation have indicated that the prosthetic socket is an important consideration in the transtibial prosthesis, as inadequate contraction of the quadriceps muscles may be due to limitations of the socket design. Continuing research into limitations of the prosthesis is necessary to allow the transtibial amputee to return to the maximum function possible.

APPENDICES

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4.11 - 4.15: HAMSTRINGS PEAK EMG

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APPENDIX 5: EMG PROFILES FOR TTA SUBJECT

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5.2: STAIR ASCENT

5.3: STAIR DESCENT

APPENDIX 1: INFORMED CONSENT FORM

QUADRICEPS ATROPHY IN TRANSTIBIAL AMPUTEES: RELATIONSHIP TO MUSCLE ACTIVATION PATTERNS IN NORMAL ACTIVITIES.

INVESTIGATOR: CAROLINE O'KEEFE
Honours Student, Prosthetics and Orthotics

SENIOR INVESTIGATOR: DR TIM BACH
Head of National Centre for Prosthetics and Orthotics

The aim of this project is to investigate the causes of thigh muscle wasting which is commonly observed in transtibial (below knee) amputees. It is proposed that the altered walking patterns of the amputee may contribute to this muscle wasting. This may be due to the reduced muscle activity occurring in the involved thigh muscles.

It is the purpose of this investigation to examine the thigh muscle activity which occurs during walking and various daily activities. During these activities a comparison of thigh muscle usage of the amputated and non-amputated limbs will be obtained.

Subjects will be required to be in attendance at the gait laboratory on one occasion only, for a duration of approximately one hour. A number of height, weight and lower limb dimensions will be made. Subjects will be asked to complete the following normal activities: level walking along a 15 metre walkway in the gait laboratory; ascending and descending a set of approximately 4 stairs; and sitting and rising from a seated position. These activities will generally be performed 3 or 4 times to enable an average muscle activity level to be obtained. Rest periods will be encouraged between activities, and subjects may stop at any time if they experience fatigue.

In order to measure and record the thigh muscle activity, surface electrodes will be placed over the subject's thigh muscles. Small sections of leg hair may need to be shaved in order to attach the electrodes, which will be taped in position. This procedure will involve no risk to the subject, and should not cause any discomfort or pain. Laboratory personnel will be in attendance at all times during testing to ensure the safety of the subjects.

The results of this study will assist investigators in understanding the causes of thigh muscle wasting which commonly occurs in transtibial amputees. If the relationship between this wasting and muscle usage in daily activities is determined, then this may have implications in future prosthesis design and/or training techniques.

You are free to withdraw your consent and discontinue participation at any time.

Any questions regarding the project titled QUADRICEPS ATROPHY IN TRANSTIBIAL AMPUTEES: RELATIONSHIP TO MUSCLE ACTIVATION PATTERNS IN NORMAL ACTIVITIES may be directed to the senior investigator, Dr Tim Bach, Head of the National Centre for Prosthetics and Orthotics (contact telephone number: 9285 5311).

If you have any complaints about this project or have any queries which the senior investigator has not been able to answer satisfactorily, you should write to the Chairperson of the Faculty Human Ethics Committee, Faculty of Health Sciences, La Trobe University, Bundoora, 3083.

I, _____, have read and understood the information above, and any questions I have asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time.

I agree that research data collected during the study may be published or provided to other researchers, on condition that my name is not used.

Name of participant: _____

Signature: _____ Date: __/__/__

APPENDIX 2

CIRCUMFERENCE OF THIGH

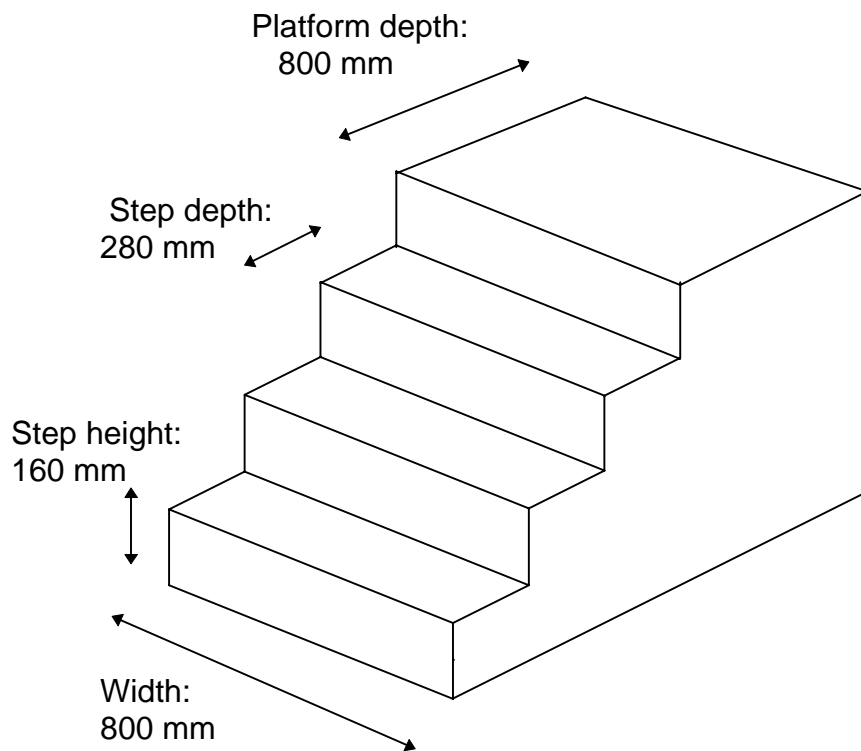
TTA Subject No.	Amputated Limb (mm)	Sound Limb (mm)	Ratio Amputated/Sound
1	600	570	1.05
2	555	515	1.08
3	420	500	0.84
4	490	525	0.93
5	560	600	0.93
6	430	490	0.88
7	495	505	0.98
8	425	460	0.92
9	425	455	0.93
10	500	545	0.92
Mean			0.95

AB Subject No.	Non-Dominant Limb (mm)	Dominant Limb (mm)	Ratio Non-Dominant/Dominant
11	440	440	1.00
12	525	520	1.01
13	475	475	1.00
14	490	485	1.01
15	450	465	0.97
16	500	500	1.00
17	545	560	0.97
18	500	515	0.97
19	490	480	1.02
20	440	440	1.00
Mean			1.00

Circumferential measurements of the thigh were taken at the height of the VL electrode placement. The difference between amputated and sound limbs was not substantially greater than that observed between limbs of able-bodied subjects. It has previously been noted that an external circumference is not an accurate measure of muscle atrophy, as subcutaneous tissue may conceal the specific thigh muscle atrophy occurring.

APPENDIX 3

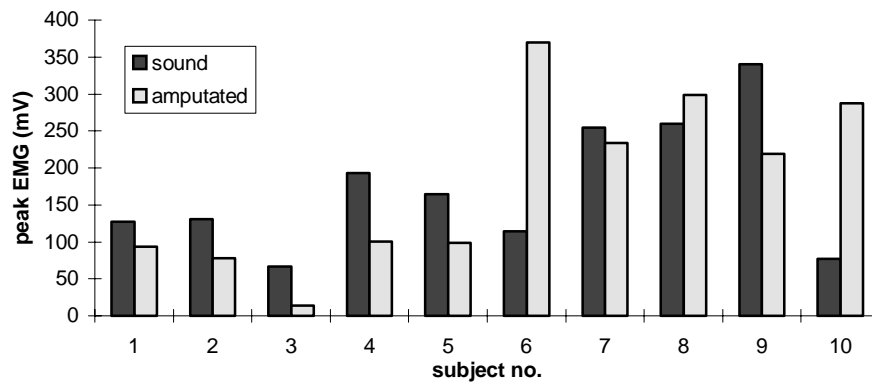
DIMENSIONS OF STAIRCASE



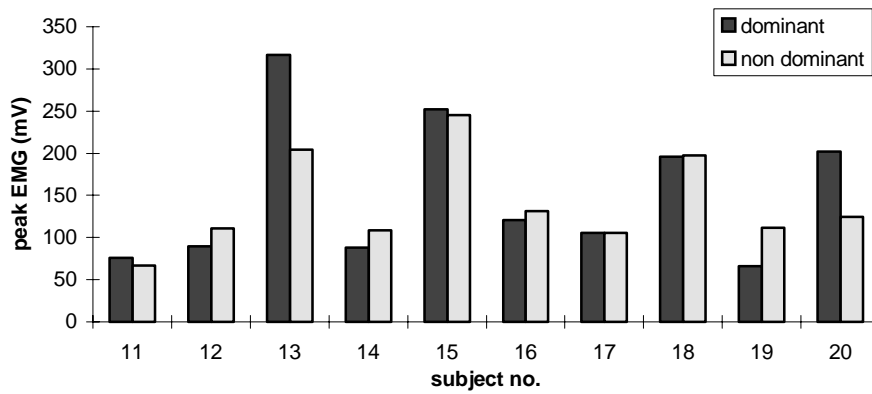
APPENDIX 4: INDIVIDUAL SUBJECT RESULTS

4.1 LEVEL WALKING: Quadriceps Peak EMG

Transtibial Amputee subjects:

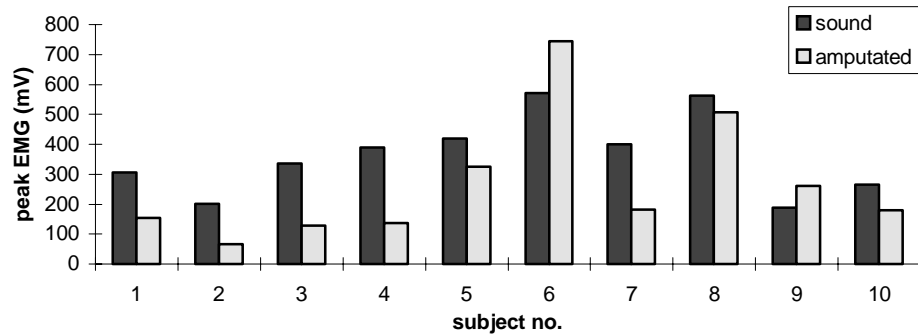


Able-Bodied subjects:

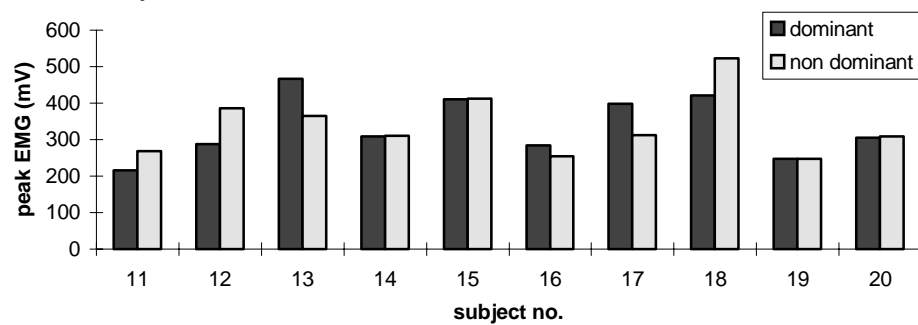


4.2 STAIR ASCENT: Quadriceps Peak EMG

Transtibial Amputee subjects:

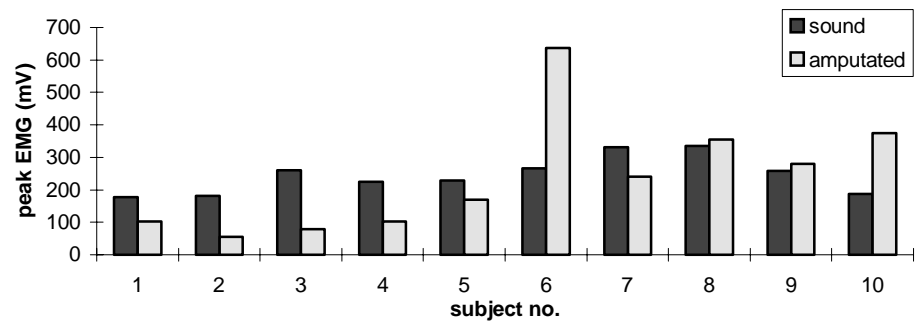


Able-Bodied subjects:

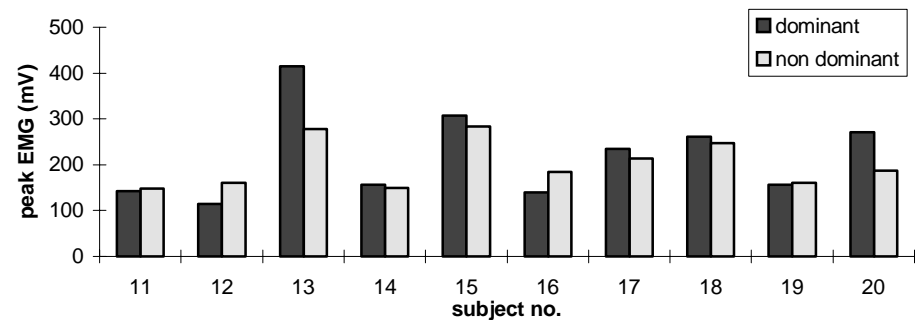


4.3 STAIR DESCENT: Quadriceps Peak EMG

Transtibial Amputee subjects:

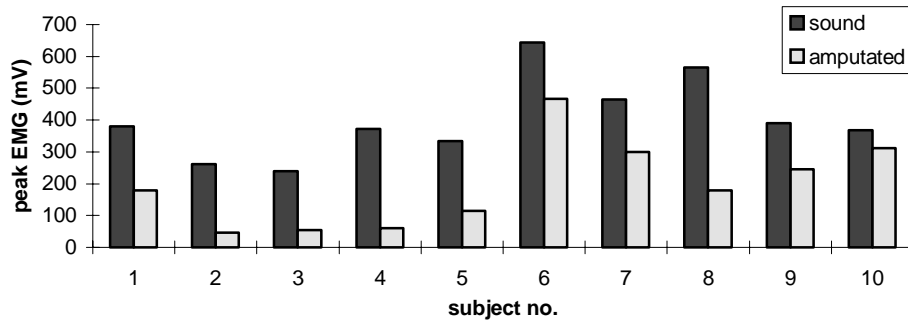


Able-Bodied subjects:

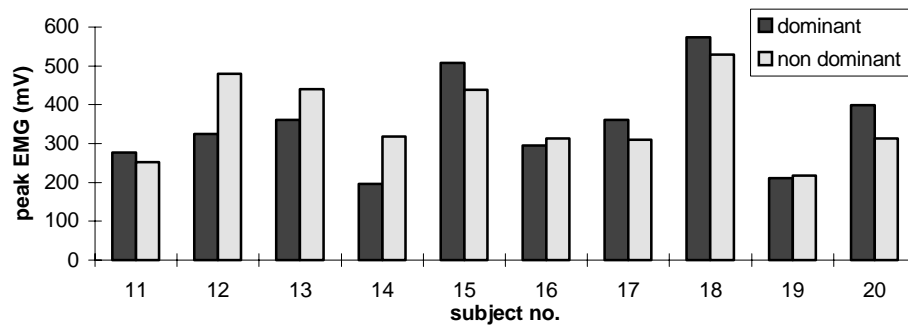


4.4 SIT-TO-STAND: Quadriceps Peak EMG

Transtibial Amputee subjects:

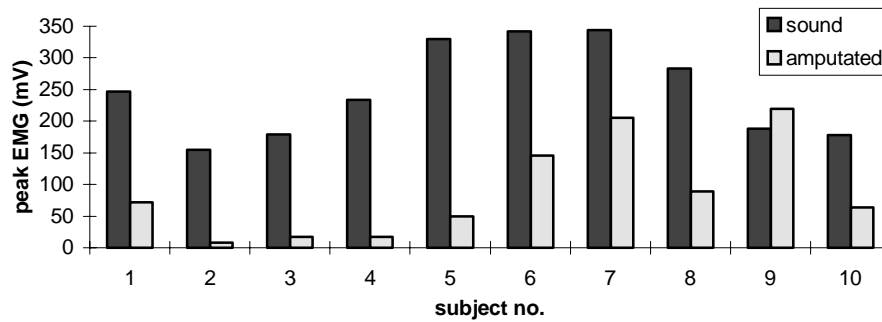


Able-Bodied subjects:

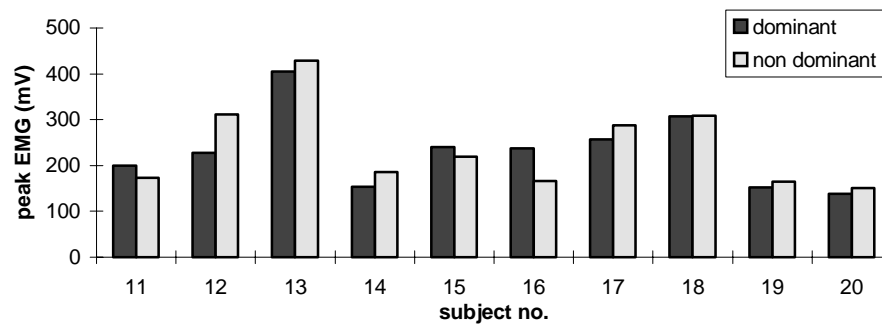


4.5 STAND-TO-SIT: Quadriceps Peak EMG

Transtibial Amputee subjects:



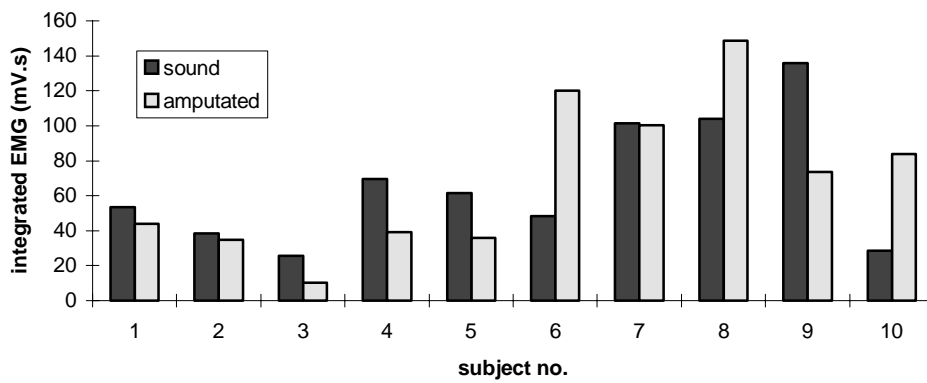
Able-Bodied subjects:



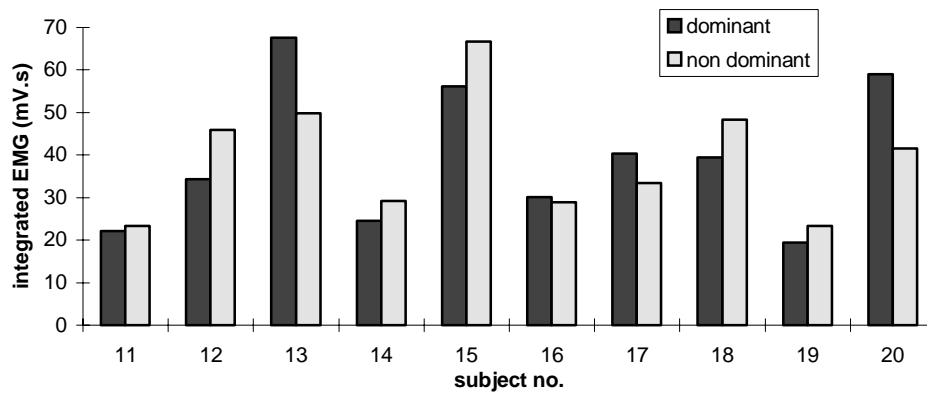
APPENDIX 4: INDIVIDUAL SUBJECT RESULTS (cont.)

4.6 LEVEL WALKING: Quadriceps Integrated EMG

Transtibial Amputee subjects:

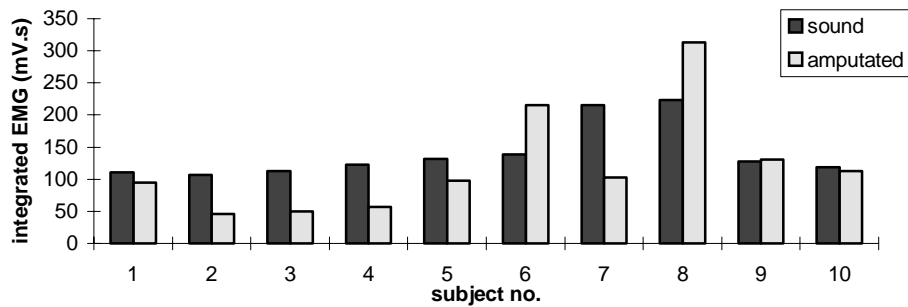


Able-Bodied subjects:

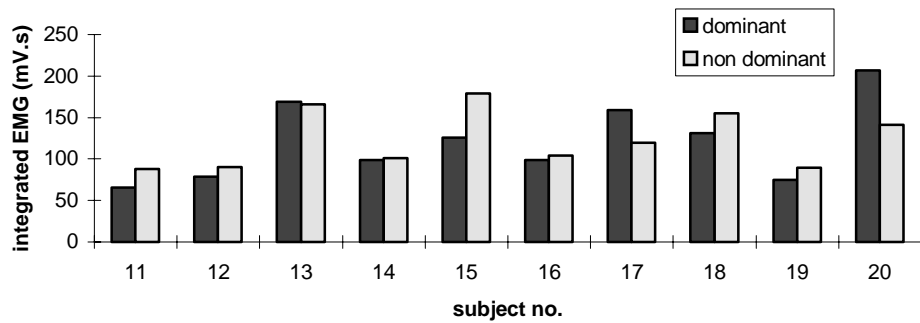


4.7 STAIR ASCENT: Quadriceps Integrated EMG

Transtibial Amputee subjects:

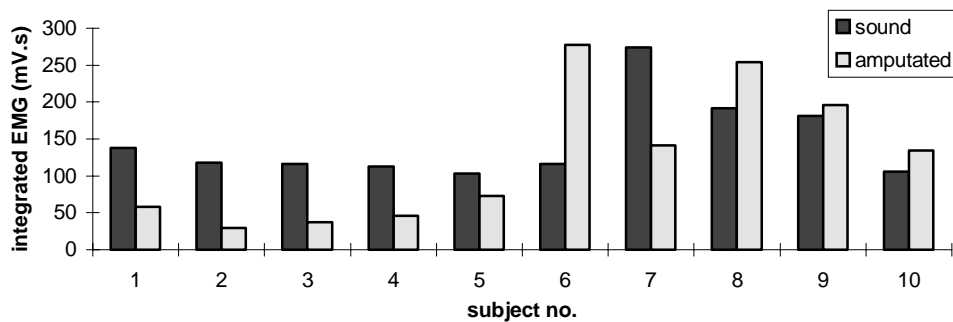


Able-Bodied subjects:

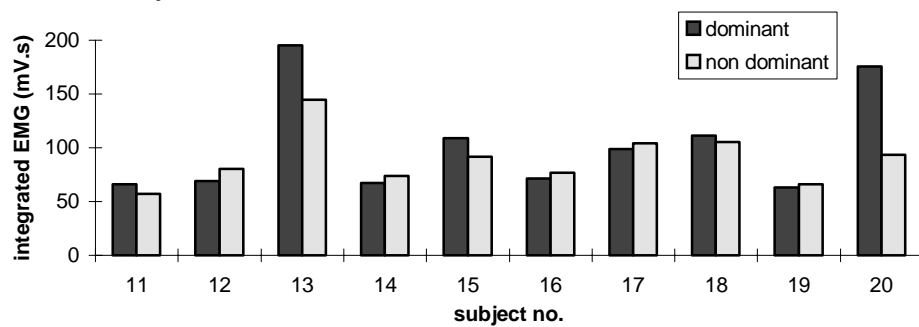


4.8 STAIR DESCENT: Quadriceps Integrated EMG

Transtibial Amputee subjects:

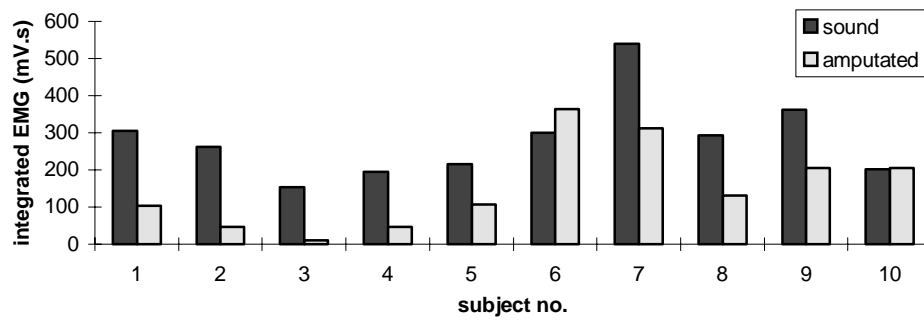


Able-Bodied subjects:

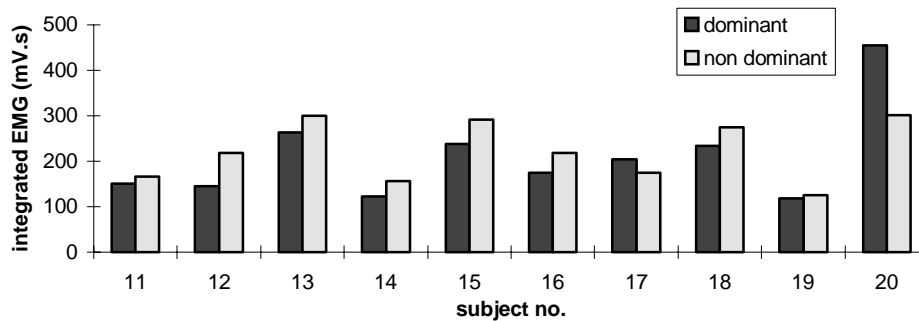


4.9 SIT-TO-STAND: Quadriceps Integrated EMG

Transtibial Amputee subjects:

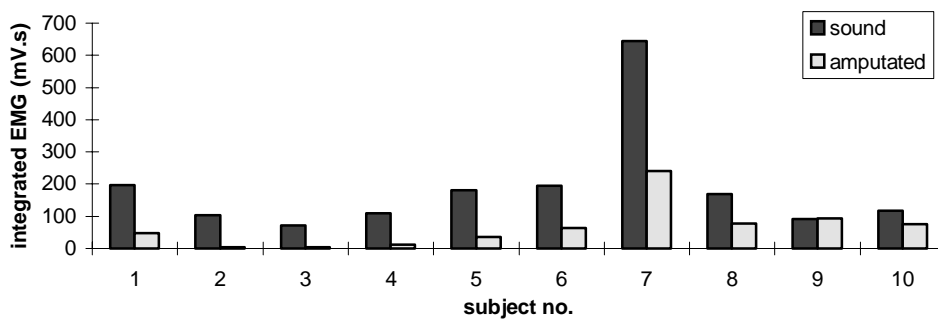


Able-Bodied subjects:

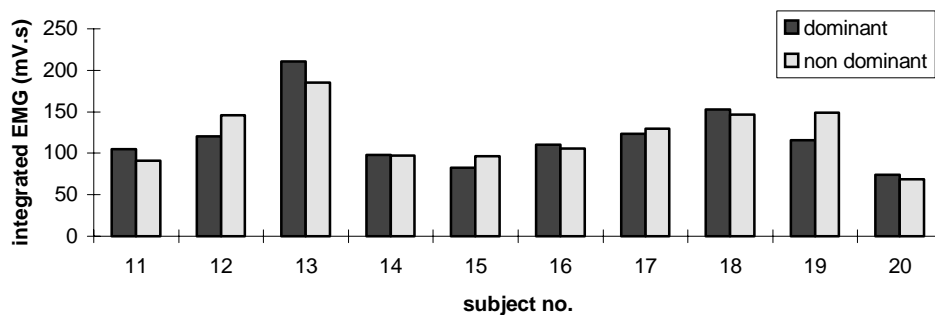


4.10 STAND-TO-SIT: Quadriceps Integrated EMG

Transtibial Amputee subjects:



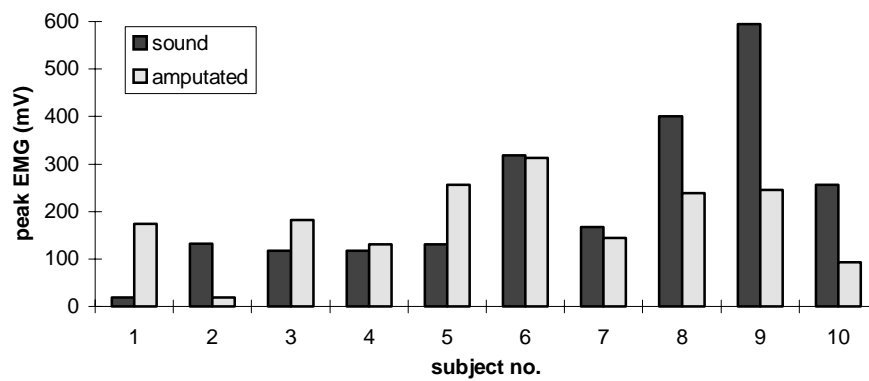
Able-Bodied subjects:



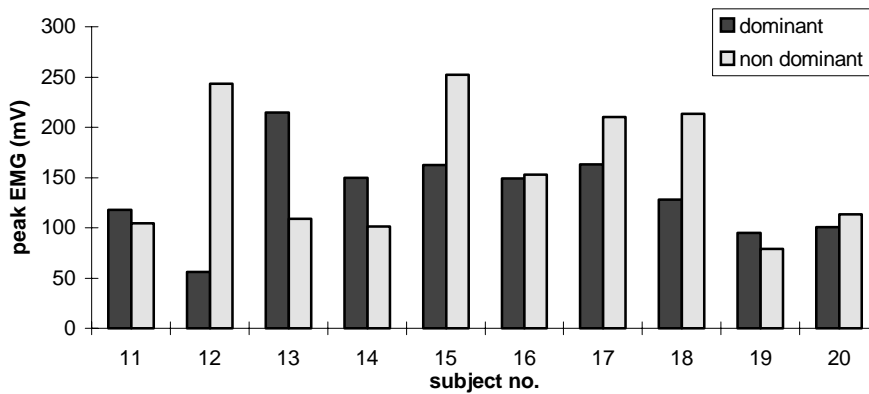
APPENDIX 4: INDIVIDUAL SUBJECT RESULTS (cont.)

4.11 LEVEL WALKING: Hamstrings Peak EMG

Transtibial Amputee subjects:

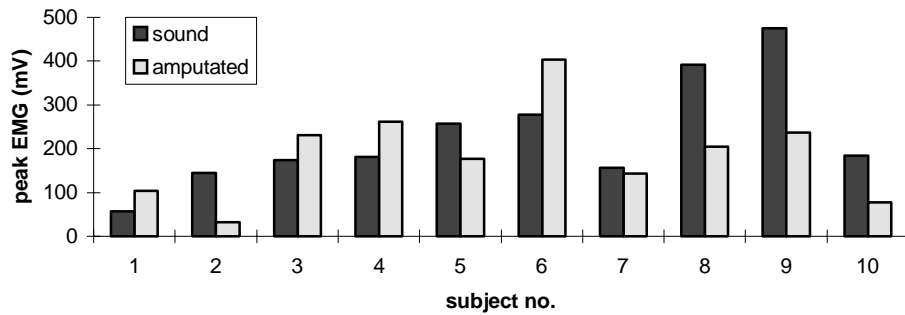


Able-Bodied subjects:

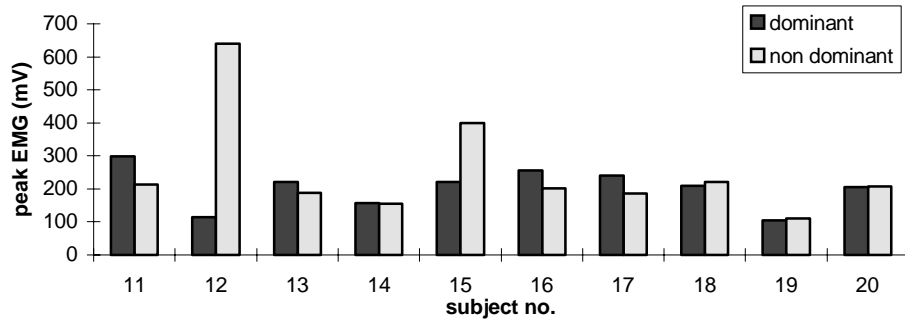


4.12 STAIR ASCENT: Hamstrings Peak EMG

Transtibial Amputee subjects:

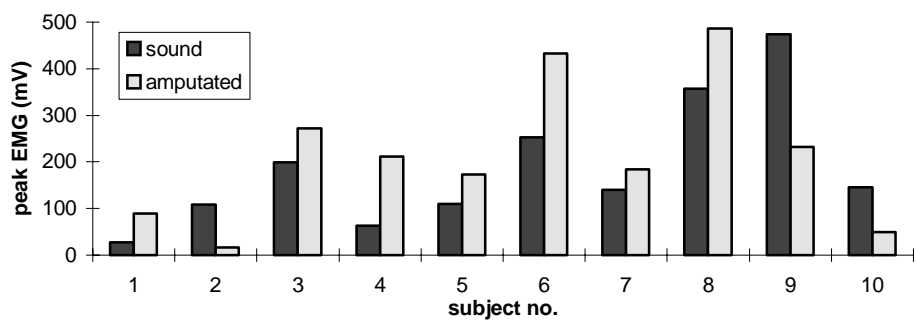


Able-Bodied subjects:

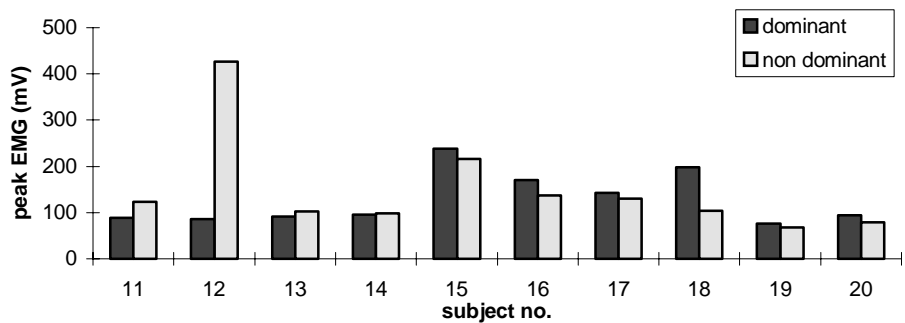


4.13 STAIR DESCENT: Hamstrings Peak EMG

Transtibial Amputee subjects:

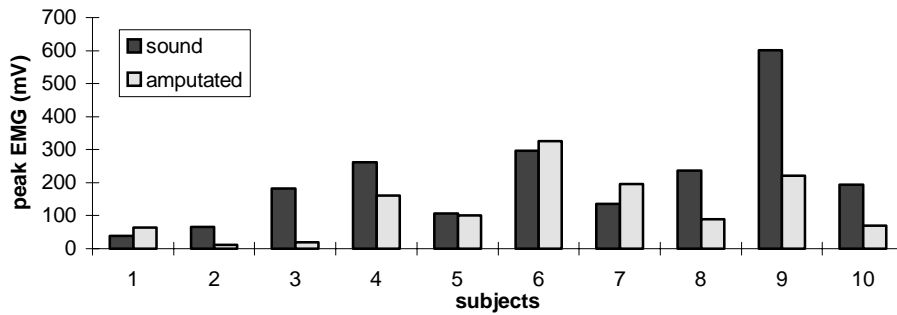


Able-Bodied subjects:

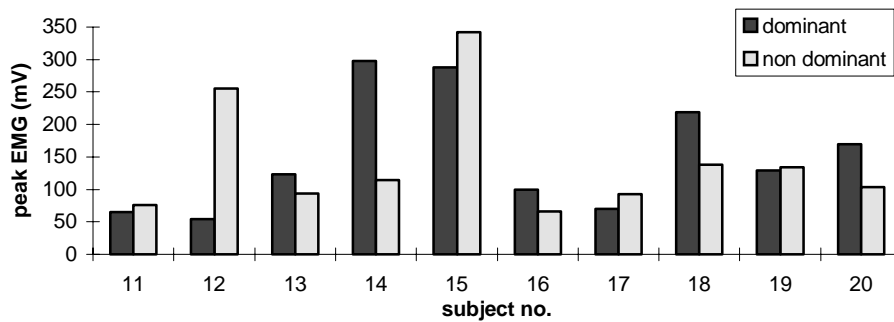


4.14 SIT-TO-STAND: Hamstrings Peak EMG

Transtibial Amputee subjects:

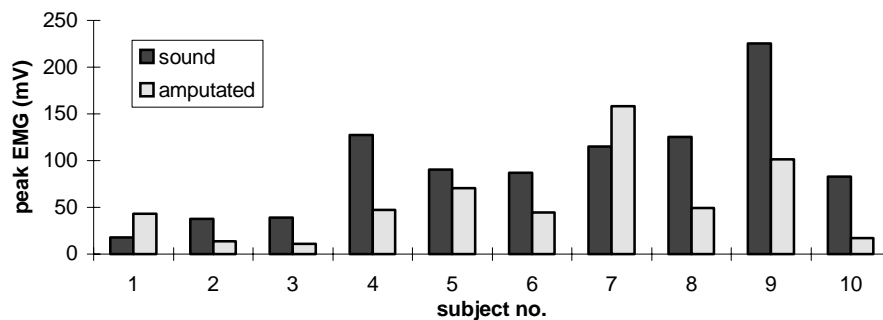


Able-Bodied subjects:

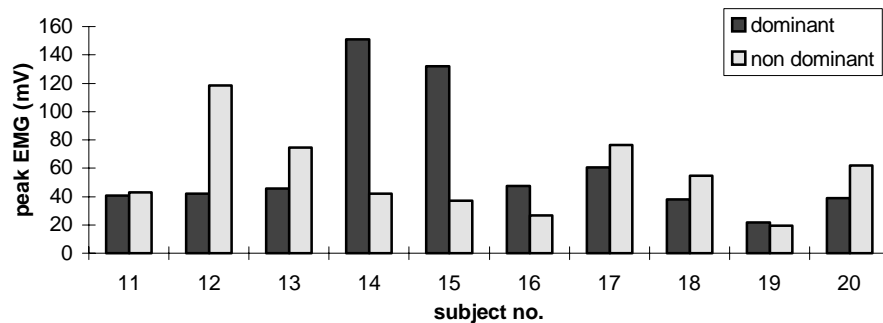


4.15 STAND-TO-SIT: Hamstrings Peak EMG

Transtibial Amputee subjects:



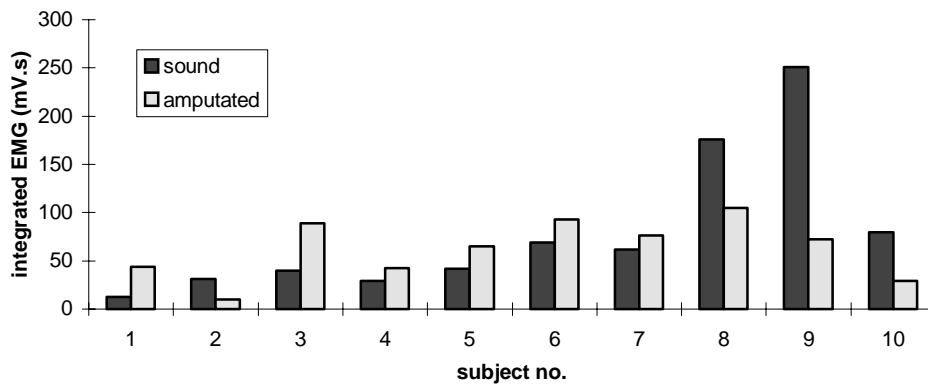
Able-Bodied subjects:



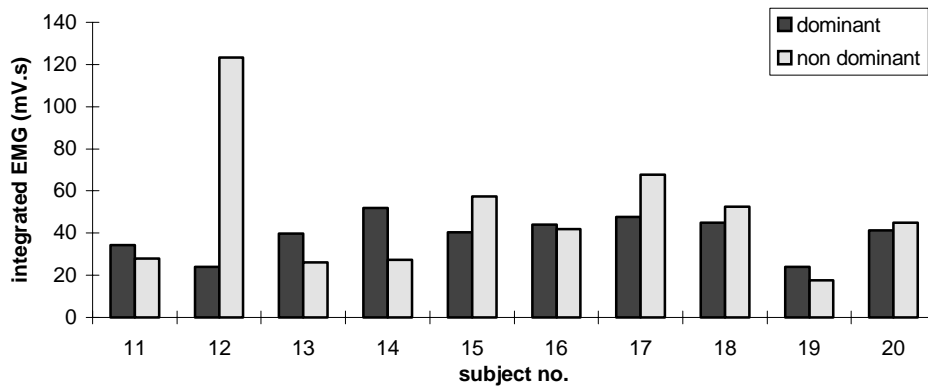
APPENDIX 4: INDIVIDUAL SUBJECT RESULTS (cont.)

4.16 LEVEL WALKING: Hamstrings Integrated EMG

Transtibial Amputee subjects:

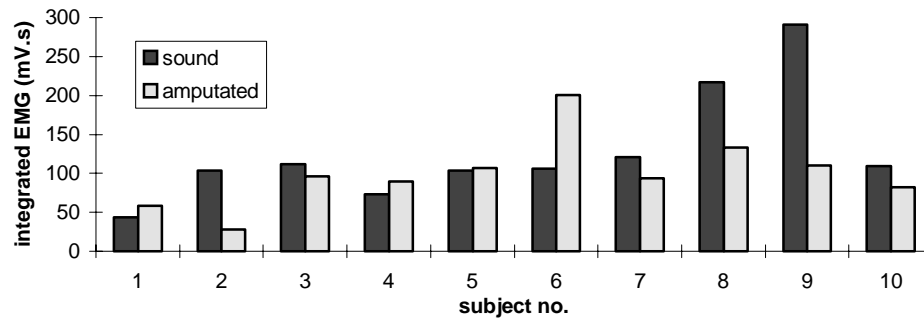


Able-Bodied subjects:

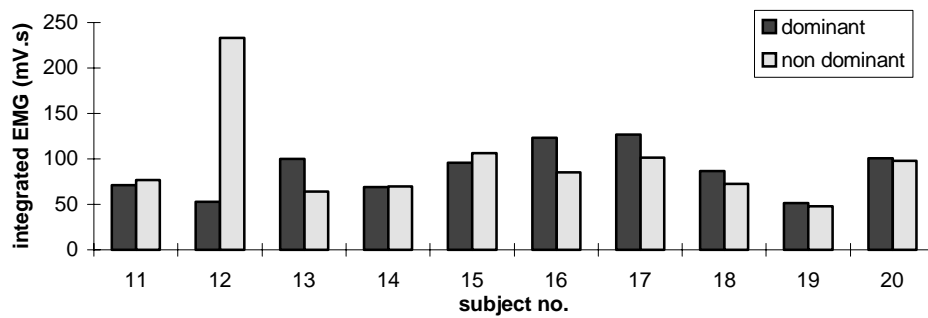


4.17 STAIR ASCENT: Hamstrings Integrated EMG

Transtibial Amputee subjects:

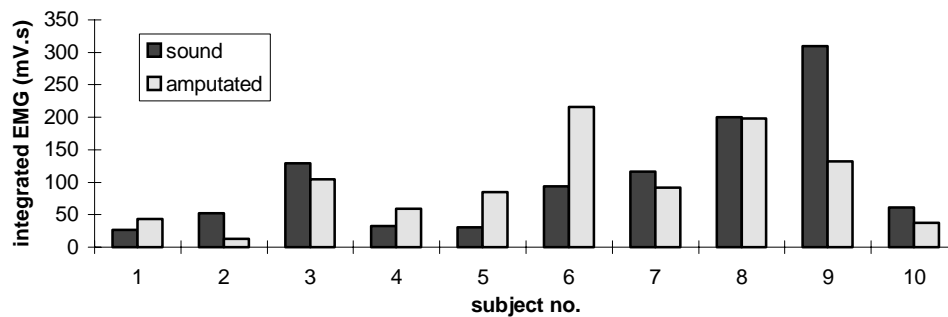


Able-Bodied subjects:

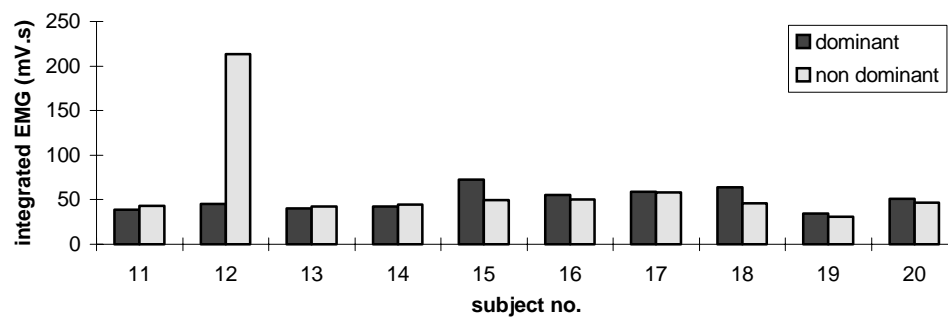


4.18 STAIR DESCENT: Hamstrings Integrated EMG

Transtibial Amputee subjects:

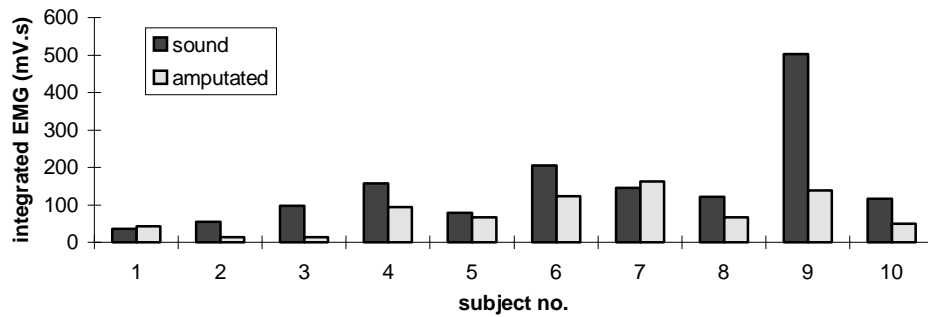


Able-Bodied subjects:

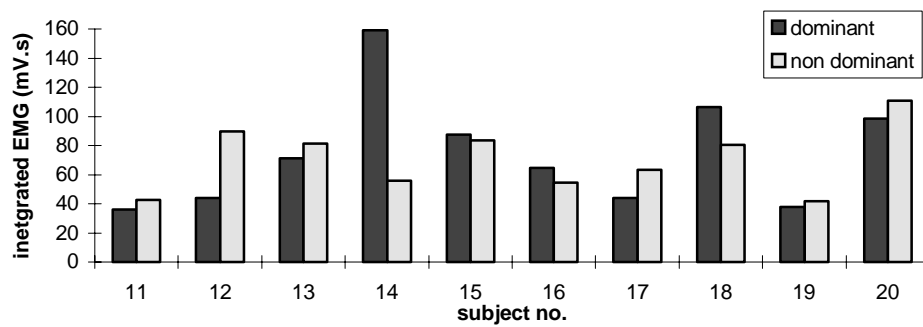


4.19 SIT-TO-STAND: Hamstrings Integrated EMG

Transtibial Amputee subjects:

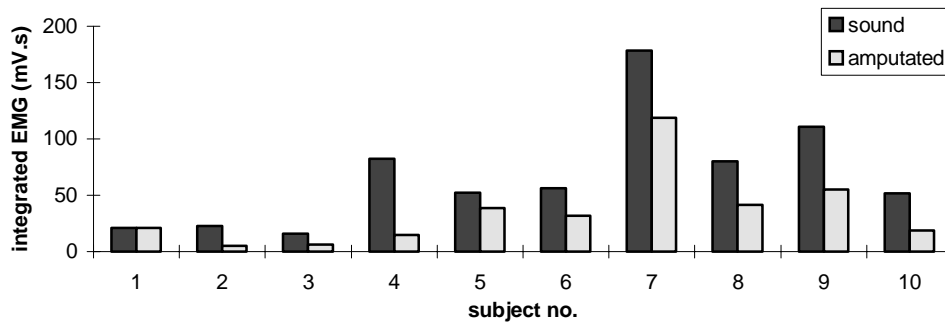


Able-Bodied subjects:

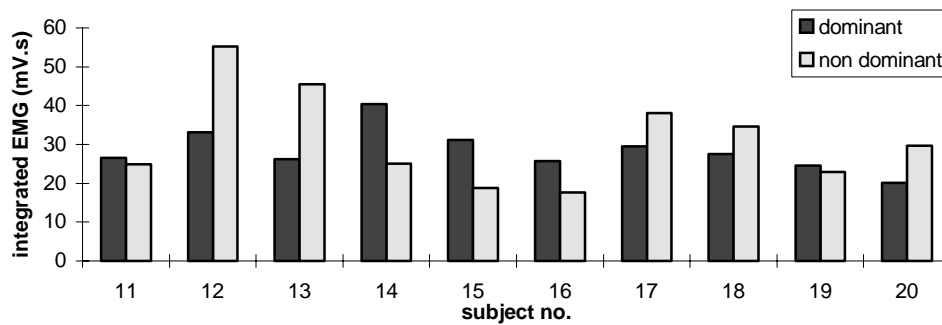


4.20 STAND-TO-SIT: Hamstrings Integrated EMG

Transtibial Amputee subjects:



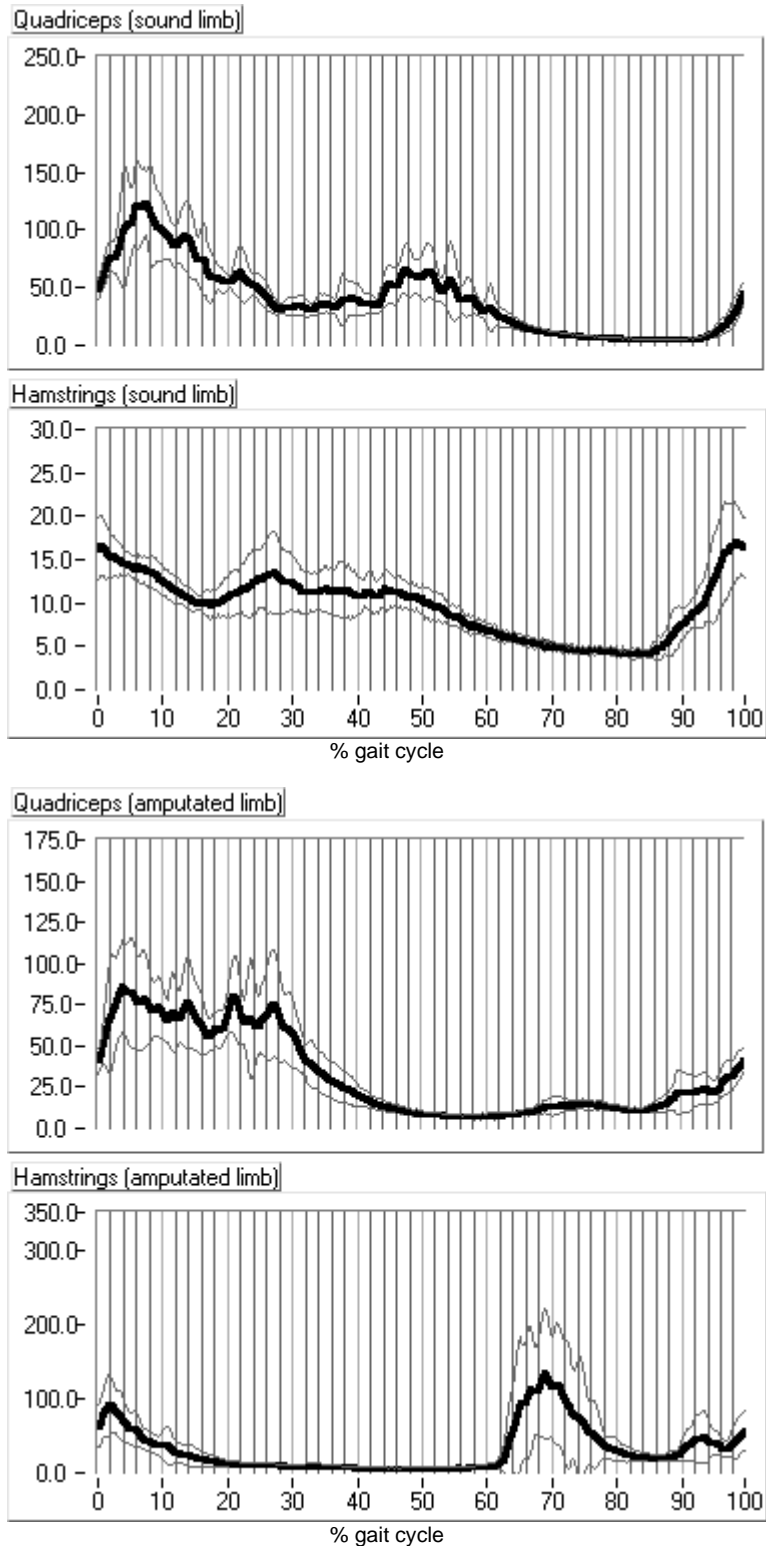
Able-Bodied subjects:



APPENDIX 5: EMG PROFILES FOR INDIVIDUAL TTA SUBJECT

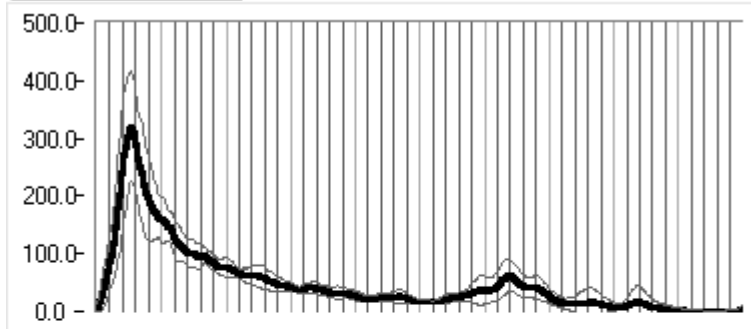
EMG profiles for quadriceps and hamstrings muscle groups, on both sound and amputated limbs are displayed for **Subject No. 1**. The activities of level walking, stair ascent and stair descent are shown (EMG measured in mV).

LEVEL WALKING

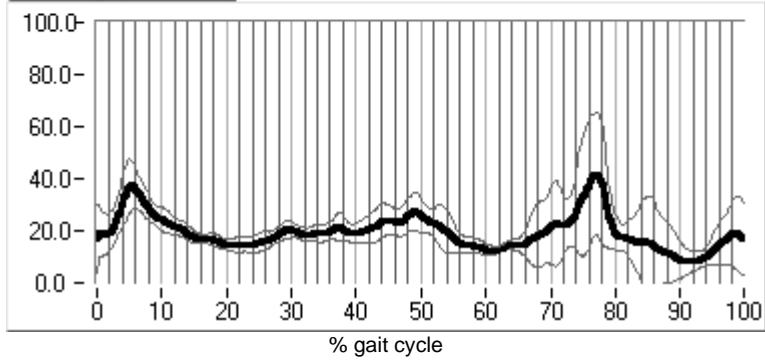


STAIR ASCENT

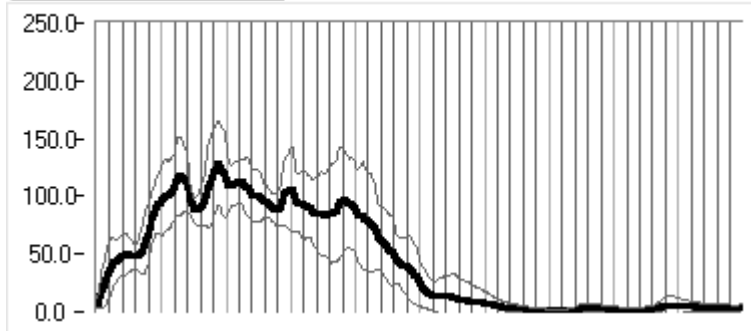
Quadriceps (sound limb)



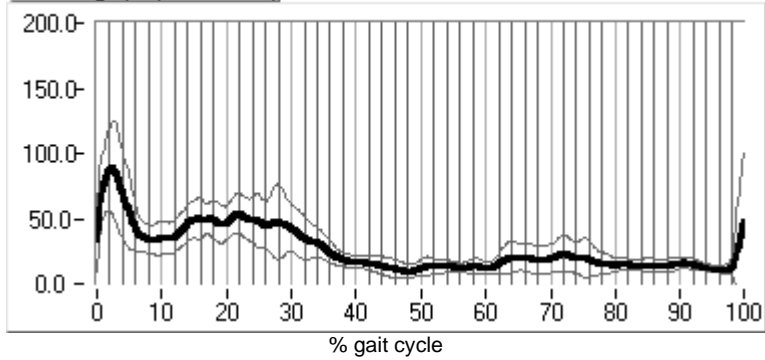
Hamstrings (sound limb)



Quadriceps (amputated limb)

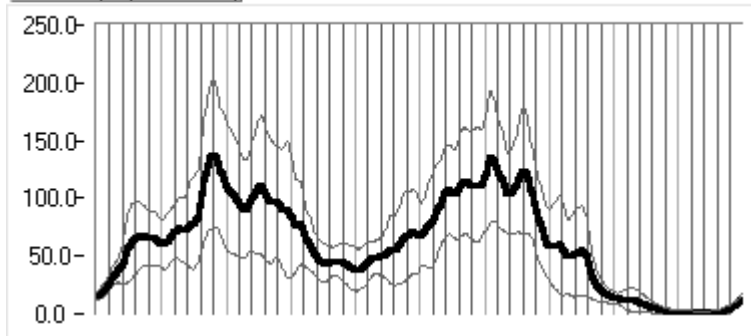


Hamstrings (amputated limb)

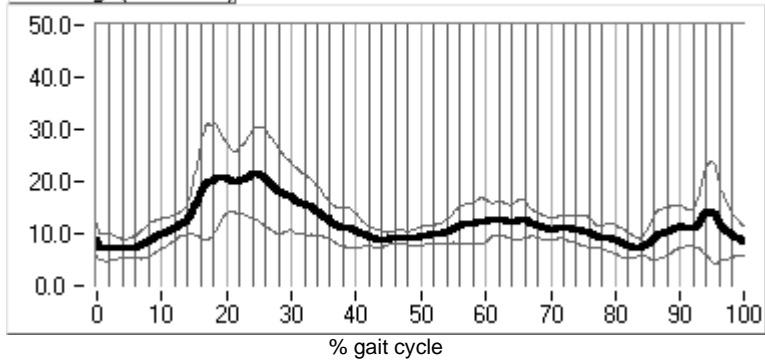


STAIR DESCENT

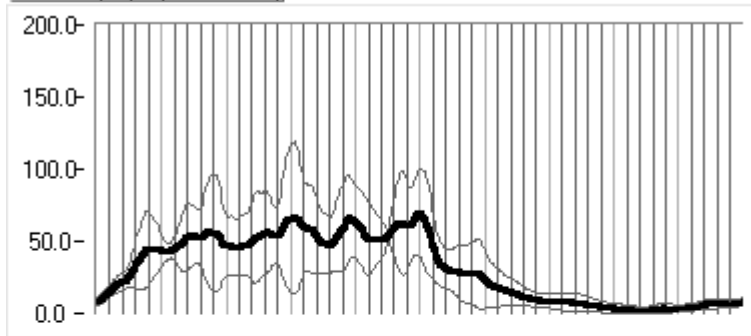
Quadriceps (sound limb)



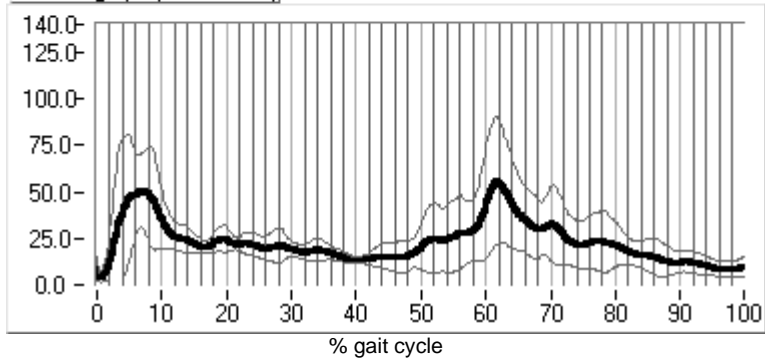
Hamstrings (sound limb)



Quadriceps (amputated limb)



Hamstrings (amputated limb)



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