

Electro-tactile sensation thresholds for an amputee gait-retraining system

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Introduction

Approximately 5000 new referrals are received every year in the UK for limb amputations [1]. Lower back pain is reported in as high as 52 - 94% of lower limb amputees, from [2]. Following discharge patients do not receive regular reviews by physiotherapists and often adopt a variety of habitual gait patterns that can lead to back pain. Circumduction is a one such pattern which is thought to contribute to lower back pain. It involves a wider than normal lateral arc of the prosthesis during swing to prevent the foot striking the floor [3]. This results in an asymmetrical movement of the pelvis and lumbar spine. An increase in transverse rotation of the pelvis in trans-femoral amputees is a contributing factor to lower back pain [4].

Feedback of kinematic data to amputees may help reduce habitual and painful gait patterns. Such feedback could also help therapists convey information to patients regarding kinematic alterations during hands-on physiotherapy in a rehabilitation gym.

Biofeedback (BFB) is a training technique emerging in many areas of neuromuscular rehabilitation [5]. It involves measuring a bodily function (such as heart rate, temperature or a movement pattern), then conveying information back to the patient to help them learn to adjust that function. BFB increases awareness of performance and is typically used in real-time during a training regime. BFB has been used successfully in many areas of neuromuscular rehabilitation, with promising results in gait re-training for a range of patient groups [5] but there is limited work in the area of amputee gait re-training.

A real-time closed-loop biofeedback training system is being developed to help trans-femoral amputees correct adverse gait patterns by providing greater awareness of gait deviations. For the current work lower limb kinematics are captured from a passive infra-red motion capture system (ProReflex, Qualysis, Sweden) whilst the patient walks on a treadmill. Hip joint angles are calculated and compared against a reference data set. The extent of gait deviation is determined in real-time from the combined coronal and sagittal hip joint angles and represented as an error vector. This will guide the delivery of an electro-tactile stimulus around the surface of the stump. However the stimulation parameters required to produce a

comfortable sensation on the thigh surface under different neuromuscular conditions are not known.

Aims

This work sought to determine if a comfortable range of electro-tactile sensations exist on the thigh of healthy volunteers, between the levels of perception and discomfort; and to determine if the normal neuromuscular activity generated by different movement patterns enhances or diminishes the ability to sense and discriminate the stimuli.

Methods

An eight-channel electrical stimulator was developed which produces asymmetrical bi-phasic waveforms with adjustment of pulse-width, frequency and amplitude. An array of annular electrodes was developed to deliver the stimulation. Each electrode pair (33 mm overall diameter) contains an active conductor surrounded by a single reference. The conductors were etched from a flexible polyimide printed circuit. A hydrogel (Amgel 803, Axelgaard Manufacturing Ltd) forms a self-adhesive skin-electrode interface.

Healthy subjects were recruited from the staff and students of the University of Surrey and participated in two 3-hour sessions.

Eight electrodes were spaced equidistant in a transverse ring around the thigh. Subjects were asked to adopt three different postures during the first session: laying supine, performing a static knee flexion whilst standing, and a static knee extension whilst seated. Due to time constraints subjects returned for a second session within one week and were asked to walk on a treadmill at their self-selected comfortable speed. Four tests were carried out to assess: sensation and discomfort threshold levels, the ability to discriminate the location of a stationary stimulus, the speed and direction of a moving stimulus.

Static thresholds: During each posture or movement, a stimulus was delivered to each electrode at 40Hz, 60Hz and 80Hz, with a fixed 100 μ s pulse width. Intensity was gradually increased and subjects were asked to indicate when they initially perceived the sensation and again when they felt the sensation was uncomfortable. Peak applied current was measured using a current probe and sensation and discomfort thresholds were found for all electrode locations during the supine and walking

tasks, and for only the electrode locations covering the most anterior or posterior aspect of the thigh, for extension and flexion tasks respectively. Subject comments were also noted.

Electrode location: During the supine and treadmill walking tasks, stimuli were delivered for 10 seconds to each electrode location randomly, at 40Hz, 60Hz and 80Hz, with a fixed 100 μ s pulse width, at the mid-point intensity between sensation and discomfort. Subjects were asked to say where the stimulation was felt. Data were reported as pass or fail.

Stimulus direction and speed: During the supine and treadmill walking tasks, stimuli were applied and moved around the array clockwise and anti-clockwise at 3 different speeds ('slow', 'medium' and 'fast'). Subjects were first given an example of each condition and then asked to give the direction and speed of 12 different speed/direction combinations. Data were reported as pass or fail.

The study received favourable consideration from the University of Surrey Ethics Committee.

Results

6 male and 7 female subjects participated (with a mean age of 27 years \pm 8, and a mean BMI of 22.3 kg/m² \pm 4.3). All threshold levels are reported as the peak applied current (milliamps). The group mean threshold levels during treadmill walking are shown in figure 1. The difference between mean sensation and discomfort levels across all electrodes reduced with frequency in all of the movement tasks (from 30.5 mA to 24.4 mA supine and 37.8 mA to 32.0 mA walking).

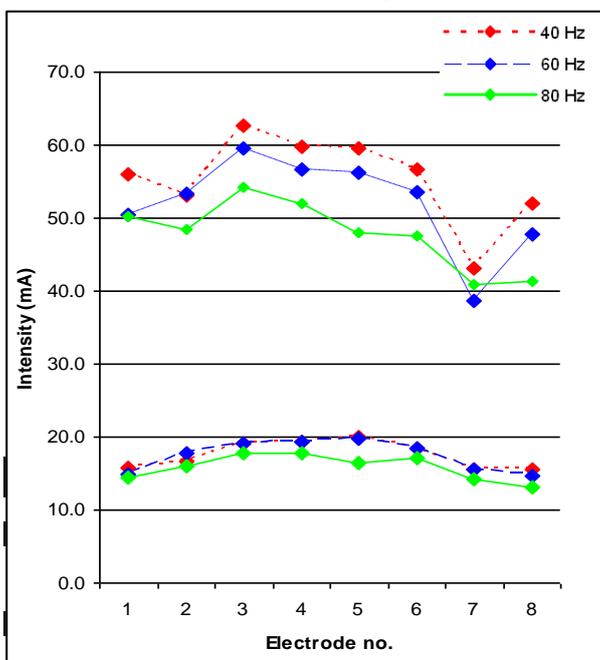


Figure 1 Group mean threshold levels subject treadmill walking, sensation (bottom) and discomfort (top)

The greatest inter-subject variation occurred at the discomfort level in all movement tasks and frequencies (the highest range being 101.1 mA, 60 Hz supine). Inter-subject variation was lowest at the sensation levels (at 60 Hz supine the range

was 20.3 mA, which was typical for the sensation levels). No pattern occurred in the difference between the treadmill and supine mean threshold levels (across all electrodes). At 80 Hz the differences were 3.1 mA and 10.7 mA at the sensation and discomfort levels respectively.

Subjects correctly identified the location of a stationary stimulus 98% of the time, and correctly described the direction and speed of a stimulus 100% of the time during all postures / movements and frequencies. Four of the five subjects who commented on the sensation at 80 Hz described it as being unpleasant.

No relationship between BMI and threshold levels was found. There was a clear gender difference, with males demonstrating higher threshold levels at sensation and discomfort.

Discussion

A separation between sensation and discomfort levels was found in all cases. This was maintained during walking and supine tasks. This is important in a biofeedback device for gait re-training where the stimulus cannot raise above the discomfort level at any time. The greater variation found at discomfort levels was expected due to the subjective nature of defining discomfort. Low threshold variation across the electrodes is desirable in order to minimise setup time, but no pattern across electrodes was found. Subjects were able to easily discriminate the location and movement of the stimulus, an important requirement for conveying information spatially to patients. The skin sensation of traumatic amputees is assumed to be largely unaffected by surgery, particularly at the mid-stump area. So it is considered that conclusions from this study can be generalised to the amputee population.

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