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The Effects of Anterior - Posterior Translations during Pedaling Movements

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Les effets de translations antéro-postérieures durant les mouvements de pédalage.

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RÉSUMÉ

La performance appropriée du corps durant les activités quotidiennes est rendue possible par l'intégration de différents systèmes. La posture et la locomotion sont réalisées grâce à cette intégration et peuvent être modulées en fonction des diverses tâches motrices lors d'activités et de situations différentes. Jusqu'à présent, il n'y a pas d'étude qui a examiné l'effet de translations linéaires antéro-postérieures (A-P) dans un mouvement rythmique comme le pédalage chez l'humain.

L'objectif de ce projet était de déterminer si les mouvements du corps vers l'avant et l'arrière peuvent avoir des effets modulatoires sur l'activité des muscles des membres inférieurs durant un mouvement de pédalage. Des changements au niveau de l'électromyographie (EMG) des muscles des membres inférieurs durant une perturbation peuvent fournir de l'information sur la modulation des influx descendantes des centres supraspinaux ou des changements dans l'excitabilité des motoneurones spinaux (Aiello et al. 1983).

Dans cette étude, l'activité électromyographique (EMG) des muscles soléaire (SOL), tibial antérieur (TA), vaste latéral (VL), et biceps fémoral - court chef (BF) a été mesurée pendant quatre conditions de pédalages: dynamique active (DA) dans laquelle le sujet devait pédaler à une fréquence de 1Hz sur un ergocycle modifié; dynamique passive (DP) où les mouvements des membres inférieurs étaient produits par le mouvement du pédalier contrôlé par le moteur dynamométrique de l'ergocycle qui reproduisait les mouvements obtenu dans la condition DA ; statique active (SA) dans laquelle le sujet orientait ses membres inférieurs dans une des quatre phases de pédalage évaluées (0°- pédale orientée verticalement vers le haut, 90°, 180° et 270°) tout en contractant le SOL au niveau observé dans la condition DA ; statique passive (SP) était similaire à la condition précédente mais sans la contraction du SOL. Les translations linéaires A-P étaient appliquées aléatoirement durant les quatre conditions de pédalage et durant les quatre phases.

Généralement, les translations linéaires A-P ont produit une augmentation de l'activité SOL durant les différentes conditions de pédalage. Dans la condition SP, la réponse était phase-dépendante ($p<0.05$). Des réponses phase-dependantes ont été observées pour les muscles SOL et VL durant la condition SA. Aucune réponse significative n'a été observée pour les translations antérieures et postérieures durant les conditions dynamiques. Cependant, il y avait une tendance pour l'EMG du SOL à être facilité après la translation antérieures. En général, la latence des réponses motrices se situait entre 100 à 150ms.

Ces résultats soutiennent des études précédentes qui ont démontrées l’effet excitateur du système vestibulaire sur l’activité des muscles des membres inférieurs SOL et VL durant les conditions statiques. Les réponses étaient dépendantes de la phase mais indépendantes des directions de translation. Les latences suggèrent que les translations A-P ont un effet modulatoire qui influence l’activité de muscles en conditions dynamique et statique.

Mots Clés : Balance, posture, locomotion, réflexes, système vestibulaire.

ABSTRACT

The proper performance of the body during daily activities is due to the integration of different systems. Posture and locomotion is the result of such integration, and can be modulated according to various motor tasks during different activities and situations. To date, no study has examined the effect of anterior-posterior (A-P) translations in humans during rhythmic movements such as pedalling.

The objective of this project was to determine if forward and backward (A-P) movements (linear translations) of the whole body have modulatory effects on the activity of lower limb muscles during pedalling movements. Changes in EMG activity of lower limb muscles during posture and locomotion to unexpected perturbations, can provide some information on the modulation of the descending outputs from the supraspinal centers or changes in the excitability of the spinal motor neurons (Aiello et al. 1983).

In this study, the EMG activity of the Soleus (SOL), Tibialis Anterior (TA), Vastus Lateralis (VL), and Biceps Femoris (BF) short head muscles were measured during four pedalling conditions: dynamic active (DA) condition in which the subject pedalled at a frequency of 1 Hz on a modified cycle ergometer; dynamic passive (DP) where the movements of the lower limbs were produced by a torque motor controlled by the signal obtained in the DA condition; static active (SA) where the subject oriented their lower limbs in the pedalling position and contracted the SOL to the level observed in the DA condition; static passive (SP), is the same as the previous one, but without contraction of the SOL. The A-P translations were applied during these four pedaling conditions and four phases (0° - top dead centre, 90°, 180° and 270°).

In general, the linear A-P translations resulted in a facilitation of the SOL activity during the pedalling conditions. During SP conditions, the response was phase dependent ($p<0.05$). Phase dependent responses were also observed in the SOL and VL muscles during the SA conditions. No significant response to either the A-T or P-T during the dynamic conditions was observed, however there was a tendency for the SOL to show excitatory effects following A-T. In general the response latencies were around 100 to 150 ms.

These results support previous studies showing the excitatory effect of the vestibular system on the of lower limb muscle activity, SOL and VL during static conditions. The responses were phase dependent but independent of the translation directions. The response latencies suggest that vestibular inputs (A-P translations) do have the late modulatory effects that influence the muscle activation in dynamic and static conditions.

Key words: Balance, posture, locomotion, reflexes, vestibular system.

1. INTRODUCTION

In order to carry out daily-life activities, such as walking, taking the metro, taking the bus or riding a bicycle, the human body has to perform various tasks under different situations. In many cases these situations cause unexpected perturbations of the body. These perturbations can make people lose their balance and sometimes even make them fall. A very good example of these unexpected perturbations is a person who, while walking inside a metro wagon, is jolted when the metro starts to move. The person must maintain his balance. The same phenomenon occurs in the opposite situation when a person, who is walking while the metro is moving, is perturbed when the metro stops.

To counter all these unexpected displacements, the human body has the ability to adapt its responses according to its environment. This ability results from the interaction between the sensory and motor systems that control the body's movements so that they can be safe, functional and effective.

The human body's main reason for adapting its responses is to protect itself from damage. These protective reactions are developed by different mechanisms, one of them being reflex responses. These responses are defined as being rapid, involuntary, and somewhat-stereotyped movements that are usually controlled in a graded way by the eliciting stimulus (Gordon 1991).

The general concept of a reflex has been around for centuries, and the term “reflex” was brought into common scientific usage by Sherrington in 1906. The term had come to denote a stereotyped and distinct neural response, which occurred largely at the sub-cortical level (e.g. spinal-cord) and which was evoked by a fixed, usually peripheral, stimulus (Zehr and Stein 1999). However, the concept of stereotyped responses in reflexes was modified in Sherrington’s later studies, in which he found that reflexes certainly had some fixed components, but the same input did not necessarily always generate the same output (Zehr and Stein 1999). Today, a reflex is defined as a coordinated, involuntary motor response initiated by a stimulus applied to peripheral receptors (Pearson and Gordon 2000).

To best understand the behaviour of the human body, it is necessary to have a general knowledge on reflex behaviours, as these motor responses reflect, in a significant manner, the activity of not only the spinal cord but the muscles as well, giving us an idea of how the body manages to control its movements, its posture and its locomotion. The reflex response is produced via the reflex arc, also called the reflex circuit, which comprises the neurological components of the reflex. One of the most studied and straightforward reflexes is the Stretch Reflex (Clarac et al. 2000). The reflex circuit involves two types of nerves: sensory nerves, which originate from the muscle, and motor nerves, which lead to the muscle. The reflex is monosynaptic because it involves only one synapse in the anterior horn cell of the spinal cord. The reflex arc in the spinal cord is one of the many factors that maintain muscle tone, which in turn helps maintain corporal posture(Gordon 1991). Muscle tone refers to the force with which a muscle resists being lengthened, or its tension (Pearson and Gordon 2000). The stretch reflex also helps the muscle resist lengthening, and thus enhances the spring-like quality of muscles while assuring their protection (Gordon 1991). Therefore, this reflex is very important for anti-gravity responses and executing different activities such as locomotion (Gordon 1991;Zehr and Stein 1999;Clarac et al. 2000). The subject of the role of reflexes in posture will be revisited later on, in the review of literature.

It is important to remark that the integration of different systems, as mentioned before, results in the proper performance of the body during daily activities. The sensory system influences the response of the motor system. Certain authors have shown, in animal studies, that the vestibulospinal tracts are responsible for increasing the activity of the ipsilateral extensor motor neurons during the stance phase of the locomotor cycle (Grillner and Hongo 1972;Orlovsky 1972b). This will be explained further later in the thesis.

Vestibular receptors are located in the middle ear and respond to linear and rotational accelerations (Kelly 1991). These peripheral receptors have been shown to be involved in the control of posture and locomotion (Orlovsky 1972a;Orlovsky 1972c;Yu and Eidelberg 1981). Also certain authors have shown, in animal studies, that electrical stimulation of the Deiter's nucleus facilitates the extensor activity in the lower limbs during locomotion (Orlovsky 1972b;Orlovsky 1972c;Yu and Eidelberg 1981;Matsuyama and Drew 2000). To date, few studies have examined the effect of unexpected translations during walking (Tang et al. 1998;Ferber et al. 2002),but the perturbations mainly stimulated the muscle and joint receptors (muscle spindles and joint afferents) of the lower limb muscles by stretching them. In contrast, in the present study, the whole apparatus onto which the subject was sitting and pedaling was translated resulting in no direct activation of muscles and joint receptors of the lower limbs.

1.1 OBJECTIVE

Considering the results of the above-mentioned studies, and knowing that posture and locomotion can be modulated according to various motor tasks during diverse activities and situations(Zehr et al. 1998;Zehr and Stein 1999;Rossignol et al. 2006), it is possible that anterior-posterior translations have an effect on the lower leg muscle activity during rhythmic movements. The goal of this project is to determine if linear translations, such as forward and backward movements of the body, have modulatory effects on the EMG activity during pedalling movements.

Changes in EMG activity of lower limb muscles during posture and locomotion due to unexpected perturbations, reflect the modulation of the descending outputs from the supraspinal centers or changes in the excitability of the spinal motor neurons (Aiello et al. 1983). In this study, the EMG activity of the the Soleus, the Tibialis Anterior, the Vastus Lateralis, and the Biceps Femoris short head muscle will be measured for the various pedalling conditions and applied anterior-posterior translations.

1.2 HYPOTHESIS

1.2.1 GENERAL HYPOTHESIS

Dynamic linear perturbations have a modulatory effect on the EMG amplitude of the lower limbs during pedalling movements, depending on the phase of the pedalling cycle and the direction of the linear perturbation, be it forward or backward.

1.2.2 SPECIFIC HYPOTHESES

In this project, the following three specific hypotheses will be evaluated. Firstly, the extensor muscle EMG amplitude will increase following rapid linear forward displacements. Secondly, the amplitude of the extensor muscle EMG will decrease according to backward rapid linear displacements. Finally, the effect of linear displacements will be modulated during different phases of the pedalling movement: the EMG amplitude will increase during the propulsion phase of the pedalling cycle and will decrease in the recovery phase.

1.3 IMPORTANCE

The importance of this study lies in understanding how the body responds to different linear translations that occur in everyday activities, how it adjusts its motor responses, and how it maintains correct posture and balance for locomotion.

1.4 LIMITATIONS

This project had several limitations. Neck movements can change the EMG responses by activation of tonic reflex of the neck (Brunia 1973;Aiello et al. 1983). To minimize and control the inputs from the neck muscle receptors (muscle spindles) during vestibular perturbations (Linear translations), the head and neck were kept fixed using a Velcro band that kept the head in permanent contact with the head rest of the ergocycle. Also, in the dynamic passive pedalling condition, during which the torque motor replaces the voluntary movements of the lower limbs, the descending inputs cannot be removed completely; however, in this study, muscle activity was controlled by monitoring the EMG signals. The analysis did not take into account pedalling cycles in which muscle activity was present.

Since the subject population included only young adults who did not have any neurological or orthopaedic problems, the results from this study cannot be applied to other populations. Finally, this study was conducted using a modified ergocycle, so the results may not be extrapolated directly to walking.

2. LITERATURE REVIEW

2.1 POSTURE

Posture is essentially the relative position of the various parts of the body with respect to one another and to the environment (Kandel.E.R et al. 2000). The purpose of any postural adjustment during upright stance, whether anticipatory or reactive, is the control of equilibrium (Hughey and Fung 2005).

The maintenance of posture is an active process regulated by a large variety of sensory and central inputs (Massion 1984). One of the mechanisms, as mentioned before, that control the posture is muscular tone (Gordon 1991), which in this case is called postural tone, and refers to the tone added to the basic tonus (muscle rigidity that helps to maintain joints in a defined position), mainly in the extensor muscles of the lower limbs, which exert a force against gravity (Massion 1984). Human upright stance is maintained by a posture control mechanism, the goal of which is to maintain the orientation of the body upright and thereby the center of mass above the base of support (Maurer et al. 2006).

Many studies conducted in postural control have been done, in order to understand its basic mechanism. Nashner (1976), performed some studies using movable platforms, and in one of his studies, where the subjects received anterior-posterior translations of the platform while standing, he observed three diferent responses in terms of latencies of the EMG activity. First, the muscle stiffness of the ankle acting immediately. Second, in some of the subjects he observed a facilitatory effect of the medial portions of the gastrocnemius muscle after the forward swaying, with a muscle response latency of 120ms after the translation was given. He referred this muscle response as the FSR (functional stretch reflex). For the other subjects, he observed a smaller increase in the EMG activity, which start no longer that 180ms period after the onset of the sway. And the third and last response he observed was the vestibular activation acting in latencies longer than 180ms. In that particular study, he concluded that, the FSR increased the ankle stiffness when this response stabilized anterior-posterior (A-P) sway motion, and could also augment stiffness above normal levels to compensate any functional loss of stiffness caused by the movement of the platform itself (Nashner 1976). With respect to the different latencies of EMG response in the subjects, he presumed that there are two mechanisms of adaptation: for the subjects that responded at 120ms after the translation was given, they used rapid FSR response to augment muscles stiffness. While the subjects that responded at 180-200 ms relied more heavily on more complex vestibular and visual inputs to augment stability provided by muscle stiffness.

Later, in 1985, (Nashner and McCollum)described the ensemble of synergies that the body brings into play to act in response to different types of perturbations during a standing position. They mentioned that to generate the appropriate postural movement in response to a perturbation, the system determines the region into which it has been displaced and then selects the control strategy appropriate to that region. In this way, they talked about how the joints play an important role in this issue: both the hip and ankle react at different times and with different strategies. After a forward perturbation of the platform, the ankle synergy (paraspinales, hamstrings, and gastrocnemius) moves the body toward the origin. Muscles on the same dorsal or ventral aspects of the leg and trunk contract at approximately the same time, and this guarantees the stabilisation of the knee during the ankle synergy movements and therefore the control of the posture. Instead, the hip synergy is composed by the abdominals, quadriceps and tibialis anterior, which in turn react to backward perturbations. They proposed that the hip synergy moves the body toward a balance position with respect to gravity but not an erect posture (Nashner and McCollum 1985). Following the previous results, one might speculate that the action and reaction of the muscle synergies depend on the direction of the perturbation.

Further on, in a study on postural responses to multidirectional leg-lifting and unexpected surface translations in static conditions, Hughey and Fung (2005) showed that balance corrections were sensitive to the perturbation direction (Hughey and Fung 2005).

Some other more complex mechanisms have been proposed as well to better understand the postural control after different perturbations. In this way, the reactive reactions have been introduced. Reactive responses, or reflexes are automatic and involve changes in segmental orientation to recuperate posture (Massion 1992). In general, one of the principal functions of reflexes is to protect the body. A brief explanation of some of the multiple factors that modulate spinal reflexes is given below.

An electrical equivalent of the myotatic reflex (e.g., Monosynaptic Stretch Reflex) exists and it is called the Hoffmann Reflex, or simply the H reflex. It is named after Hoffmann, who first described it in 1918 (Hugon 1973;Edamura et al. 1991;Misiaszek 2003). The H reflex is normally obtained in a few muscles (Desmedt and Godaux 1978). Once triggered, the impulse travels along the Ia afferent fibres through the dorsal root ganglion, and is transmitted to the anterior horn where it synapses on an alpha (α) motor neuron. The impulse travels from the α motor neuron to the neuromuscular junction, and generates a motor potential that produces a muscular contraction. The H reflex can therefore be used to assess the excitability of the neural components of the reflex arc (Schieppati 1987;Misiaszek 2003).

The H reflex amplitude can be modulated by many factors such as muscle activity, a person's limb positions and body orientation.. During voluntary contraction of the Soleus, the Soleus H reflex is facilitated. As the level of contraction increases, so does the H reflex amplitude. Similarly, when a release task begins, the H reflex amplitude is inhibited depending on the degree of contraction until the muscle relaxes (Schieppati et al. 1986;Schieppati 1987). Contraction of the antagonist muscle also modulates the H reflex amplitude (Schieppati et al. 1986;Schieppati 1987). Voluntary dorsiflexion of the foot provokes an inhibition of the H reflex (Schieppati 1987). Part of this modulation is explained by reciprocal inhibitory effects which, in this case, refer to the Soleus inhibition through the synapses between the descending pathways leading to the dorsiflexors, the interneurons, and the Soleus motor neurons. Activity in other muscle groups that are distant to the ones being measured modulates the excitability of the spinal cord. Contraction of the upper extremity muscles, or performing the Jendrassik maneuver (JM), enhances the amplitude of the Soleus H reflex (Tsuruike et al. 2003).

The person position (Hugon 1973;Brunia 1973) is another factor that modulates reflexes. For example, changes in body orientations modulate spinal reflexes in relation to body posture maintenance (Knikou and Rymer 2003). Knikou and Rymer found that changes in body orientations induced a significant facilitation of the Soleus H reflex amplitude that was independent of angular stimulation (change in the join position) or the direction of movement. Changes from one position to another modify the spinal cord's excitability and in turn the muscle activity. The amplitude of the Soleus H reflex is decreased in the upright standing position compared to other postural conditions such as sitting, lying prone or standing with back support (Kawashima et al. 2003) Also, simple changes to the head position, which affect the labyrinthine influence on the spinal cord, will produce variations in the reflex responses (Hugon 1973).

In addition, certain authors have demonstrated that static tilts in the sagittal plane, irrespective of their direction, result in an increase in the Soleus H reflex (e.g., the H reflex is minimal at 90°, or when the body is vertical) (Chan and Kearney 1982b). Aiello et al. have shown that there is a linear relationship between static body inclinations in the sagittal plane and the H reflex amplitude (Aiello et al. 1983). They observed an increase in the Soleus H reflex as the body was displaced from a horizontal to a vertical position (i.e., from supine to standing) and vice versa. They also showed an inhibition of the ipsilateral Soleus H reflex and an increase in the contralateral Soleus H reflex with static inclinations of the head and body in the frontal plane (Aiello et al. 1992).

Paquet and Hui-Chan (1999) demonstrated that dynamic forward inclinations of the head in the sagittal plane produced a marked inhibition of the Soleus H reflex 30 to 70 ms and 151 to 190 ms after the onset of head acceleration in the sagittal plane (≈0.7 g). Similarly, a dynamic ballistic rotation of the head (i.e., 90° head rotation to the left) produced an inhibition of the contralateral Soleus H reflex, while the ipsilateral response remained unchanged (Anson and Kasai 1995). In contrast, Scarpini, et al. (Scarpini et al. 1991) reported a facilitation of the Soleus H reflex with a dynamic rotation of the head and body (e.g., sitting in a rotating chair), irrespective of a clockwise or counter-clockwise direction of movement.

2.2 SENSORY SYSTEM AND LOCOMOTION

There are different types of senses (visual, auditory, vestibular, and somatosensory) that modulate posture and locomotion in several ways. Sensory inputs can have global influences in allowing, preventing, or selecting motor patterns (Rossignol et al. 2006).

These sensory inputs can participate in the correct positioning of the feet in uneven terrain or in response to obstacles. They can also modify the frequency of the muscle discharge pattern, its intrinsic structure, or its amplitude within its component subphases of the locomotor cycle (Rossignol et al. 2006). The present study will focus mainly on the somatosensory and vestibular afferents that modify the rhythmic, locomotor-like pattern of pedalling.

2.2.1 THE ROLE OF THE CUTANEOUS INPUTS DURING LOCOMOTION

As mentioned earlier, in order to protect itself from injury, pain or uncomfortable sensation the human body responds with reflexes that modulate its posture or locomotion.

The main role of cutaneous inputs appears to be the correct positioning of the foot during normal walking or the correct adaptive limb responses to perturbations in different phases of the step cycle (Rossignol et al. 2006). During some experiments conducted with chronic spinal cats walking with the hindlegs on a treadmill Forssberg et al (1975) showed that touching the dorsum of a foot during swing phase resulted in a short latency activation of the flexor muscles of that limb. In contrast, the same stimulus applied during the stance phase resulted in an enhanced extensor muscle activity (Forssberg et al. 1975). These authors coined the term "reversal reflex" when referring to this phenomenon and it has since been used by many others (Lisin et al. 1973;Forssberg et al. 1975;Bélanger and Patla 1984;Zehr et al. 1998)

On the other hand , in decorticated kittens, the "tactile placing" reflex (Forssberg et al. 1974), can be elicited by light touch to the dorsum of the foot. It results in a flexion during which the limb is brought forward followed by an active extension and a subsequent placing of the foot in a more rostral position in contact with ground.

Unexpected perturbations during walking can also change the cycle duration (Forssberg et al. 1975). These authors demonstrated that the normal cycle duration varies from 1 to 1.2 sec. but when the stimulus was given in the swing phase, the cycle was prolonged in about 100ms, whereas when it was presented in stance phase the cycle remained unchanged. Moreover, if the stimulus was presented during the late portion of the stance phase phase, the cycle duration could be shortened by approximately 200 ms (Forssberg et al. 1975). Also, when the stimulus was given in the stance phase, the cycle and interlimb coordination could change to gallop.

In humans, the responses obtained by cutaneous stimulation may vary depending on the intensity, type, location of the stimulus and the phase of the step cycle where the stimulation is given. In general, electrical stimulation to cutaneous nerves during locomotion produces reflexes that, as in the cats have ipsilateral as well as contralateral effects (Lisin et al. 1973;Forssberg et al. 1975;Bélanger and Patla 1984;Zehr et al. 1998). High-intensity stimulation of the sural nerve applied on the lateral surface of the ankle inhibits the gastrocnemius muscle during the mid stance phase during locomotion, while during the swing phase a significant reduction in the plantarflexion occurs (Zehr et al. 1998). These results are similar to those of another study where a high intensity electrical stimulation was applied to the second toe during locomotion (Bélanger & Patla, 1987). They found the withdrawal reflex changed during the stance and swing phases in the stimulated limb. (Bélanger and Patla 1987).

Significant flexion of the knee was observed following sural nerve stimulation, particularly during the mid- to late swing phase. This was associated with an increased activity of the vastus lateralis, which would be expected to extend the knee in preparation for foot contact (Zehr et al. 1998). In contrast, applying medium intensity stimulation to the sural nerve resulted in ankle plantarflexion and eversion during the stance phase; also with a facilitation of the tibialis anterior muscle. Excitatory responses in the biceps femoris and in the vastus lateralis also occurred during stance phase (Zehr et al. 1998).

The reversal reflex is also observed (Lisin et al. 1973) in humans. Electrical stimulation of the sural nerve usually evokes a flexor reflex at rest as well as during walking, but the flexor reflex becomes weaker during walking. On the other hand, in subjects with hemiparesis, the same stimulus that induces a flexor reflex at rest evokes an extensor reflex during walking.

It seems very clear that the responses to cutaneous perturbation during locomotion are to protect the body from losing posture, keep balance and continue with the locomotion pattern, with a facilitatory or inhibitory modulation depending on the phase of the cycle, the type of perturbation and localization of the stimulus.

2.2.2 MODULATION OF MUSCULAR REFLEXES DURING LOCOMOTION.

Muscular reflexes are also modulated during locomotion. Numerous studies have demonstrated that the amplitude (gain) of the muscular reflex is modulated during rhythmic movements such as walking and pedalling (Capaday and Stein 1986;Brooke et al. 1992). They act to maintain balance and ensure a stable walking pattern throughout the step cycle (Zehr and Stein 1999). These studies have shown that the amplitude of the Soleus H reflex in humans is strongly modulated according to the phase of the locomotor cycle. During walking, the Soleus H reflex is inhibited during the swing phase, but it gradually increases during the stance phase (Capaday and Stein 1986;Schneider et al. 2000). Brooke et al. (1992) observed that during stationary pedalling, the amplitude of the soleus H reflex increased during the power phase, which corresponds to the leg extension; and during the recovery phase the amplitude of the H reflex was decreased. They reported that it was not necessary to have active movements, since changes in the H reflex amplitude were observed not only during pedalling movements, but also when the limbs were oriented in various static pedalling positions (Collins et al. 1993).

This modulator pattern during pedalling was also seen in other experiments by Boorman et al. (1992). While the subjects were pedalling, they clearly observed a considerable modulation of the soleus H reflex. During the downstroke portion of the pedallig cycle the amplitude of the H reflex was very high, as oppsed to during the upstroke portion, where the amplitude of the H reflex was lower. They compare these results to the previous studies by Capaday and Stein (1986;1987), and they suggest that the downstroke portion of the pedalling cycle could be considered similar to the stance phase of gait and the upstroke portion equivalent to the swing phase. They also observed that the higher amplitude of the H reflex obtained during the downstroke portion of the pedalling cycle was parallel to the increasing Soleus EMG background (Boorman et al. 1992). During the passive conditions in this experiment, the H reflex obtained was the same at each of the pedalling positions they tested. However it has been demonstrated by Brown et al (1993) that modulation of the amplitude of soleus H reflex also can occur independent of concurrent muscle activity (Brown and Kukulka 1993).

Some other studies (Brooke et al. 1992;Zehr et al. 2001) have also shown a greater soleus H reflex during the power phase (leg extension phase) of the pedalling cycle and a smaller one during the recovery phase. More specifically, the soleus H reflex reached a maximum when they were evoked at the end of the first phase of the pedalling cycle (at approximately 90° forward with respect to the top dead centre) and they became progressively smaller as the pedalling cycle advanced (Brooke et al. 1992). The H reflex modulation during cycling was also observed in the quadriceps muscles (Larsen and Voigt 2006). These authors showed that the amplitude of the quadriceps H reflex was high during power generation in downstroke (between 0° to 180°) and it was inhibited during the upstroke phase (between 180° to 360°) of the pedalling cycle (Larsen and Voigt 2006).

Moreover, many authors have demonstrated that H reflexes are not only "phase-dependent" but also "task-dependent" (Stein and Capaday 1988;Brooke et al. 1991). For example, when the participant went from standing to walking, the reflex gain (output signal/input signal) was significantly reduced. However, Zehr et al. (1999) suggested that in the swing phase during walking, cutaneous and stretch reflexes perform stumble corrections and swing limb trajectory stabilization, and during the stance phase, the reflexes help produce propulsion forces.

2.2.3 THE ROLE OF THE VESTIBULAR SYSTEM DURING LOCOMOTION

Brainstem descending pathways play a critical role in the initiation and control of motor behaviours in vertebrates (Bussieres et al. 1999). The vestibulospinal tract is one of the descending pathways having an influence on locomotion control (Orlovsky 1972b). It originates in the lateral vestibular nucleus, also known as Deiter's nucleus (Kelly 1991). In some invertebrates as the lamprey, two main systems project to the spinal cord. One of them is the vestibulospinal system (Bussieres et al. 1999), which relays excitatory inputs to the other descending system, the reticulospinal system (Pflieger and Dubuc 2004) which at the same time makes synapses with spinal MN and IN involved in locomotion (Bussieres and Dubuc 1992).

Other studies have demonstrated that electrical stimulation of Deiter's nucleus (Orlovsky 1972b;Orlovsky 1972c;Yu and Eidelberg 1981;Matsuyama and Drew 2000) during locomotion in thalamic and mesencephalic cats, strongly facilitated the activity of the extensors during the stance phase of the step cycle. In contrast, electrical stimulation did not have any influence on period in these muscles during the swing phase. The same stimulation produced a slight increase in the extensor activity while at rest in comparison to locomotion which leads to the assumption that the vestibulospinal pathway has a greater effect during locomotion (Orlovsky 1972b;Orlovsky 1972c). Partial destruction of Deiter's nucleus resulted either in a disappearance of the stepping movements of the ipsilateral limb, or in a decrease of the extensor activity during locomotion (Orlovsky 1972c;Matsuyama and Drew 2000). Moreover, bilateral destruction of the vestibular nuclei and their projections to the spinal cord in cats also produced severe deficits in posture and locomotion (Yu and Eidelberg 1981). In the early stages, the animals lost their ability to stand, walk, and feed themselves, but these abilities were gradually regained. How these functions are recovered following their destruction is not yet known. The vestibular system therefore seems to play a role in the central control of locomotion by selectively enhancing the extensor muscles during the step cycle.

2.2.3.1 REFLEX MODULATION BY VESTIBULAR SYSTEM

As previously mentioned, the lateral vestibulospinal tract, which has fibres originating from Deiter's nucleus, has a pronounced facilitatory effect on alpha (α) and gamma (γ) motor neurons that innervate extensor muscles in the limbs (Orlovsky 1972b;Orlovsky 1972c). Kots & Yanov (cf (Lacour et al. 1974), used the monosynaptic reflex method to demonstrate that electrical stimulation of the vestibular receptors modifies the excitability of spinal motor neurons. They saw a particular facilitation of the H reflex 100 ms after the vestibular perturbation was applied.vestibular-system receptors react to accelerations or decelerations of the head (Kelly 1991). These receptors are so sensitive that they respond to accelerations as small as $0.1^{\circ}/s^2$ and 0.06 m/s^2 for angular and linear movements, respectively (Benson et al. 1986).

The vestibular system has both the sensory and the motor characteristics that would be required by a neural system subserving automatic postural responses (Horak et al. 1994). In some studies where the subjects stood in a movable platform and received surface translations in different directions (Henry et al. 1998), and where the subjects received not only inputs from the translations, but also received inputs from the muscle stretch to that translation, it was suggested that postural coordination is a complex interaction of central and peripheral information. Central mechanisms may influence the timing of muscle activation, and peripherally mediated mechanisms may influence the magnitude of muscle activation (Henry et al. 1998).On the other hand, many studies have shown that different vestibular perturbations can modulate the excitability of the spinal cord. Paquet et al. (1999) showed that dynamic forward whole-head-and-body tilts decreased the amplitude of the H reflex. These tilts produced two phases of H reflex inhibition (at 30-70 ms and 191-230 ms after head acceleration) separated by a phase of disinhibition (100-110 ms after head acceleration). It was determined that the labyrinthine inputs were responsible for most of the first inhibitory phase. A decrease in the H reflex excitability during dynamic whole-head-and-body tilts could possibly prevent a strong stretch reflex from destabilizing the standing balance during the tilt (Paquet and Hui-Chan 1999). They also suggested that one source for the inhibitory influence could be exerted via presynaptic inhibition of the Ia terminals by the vestibulospinal tract. In contrast, static forward whole-head-and-body tilts evoked an increase in the H reflex amplitude (Chan and Kearney 1982a).

In other studies by Aiello et al. (1983) with healthy participants, the amplitude of the H reflex also changed according to the body's orientation relative to gravity. These authors demonstrated that different body tilts have an influence on the excitability of motor neurons, which is supported by changes in the H reflex. They concluded that the vestibular system also exerts an influence on the anti-gravity muscles in static tilts, and adequately counteracts gravity.

In lateral tilting in humans (Aiello et al. 1992), tonic labyrinthine reflexes acted on the muscle tone of upper and lower limb muscles asymmetrically and in the opposite direction. Lateral tilting of the longitudinal body axis with the neck fixed in a sitting position produced flexor tone inhibition in the upper limb that was tilted down, and facilitation in the flexor tone of the contralateral upper limb.Similar results were obtained for the upright position, lateral tilting of the whole subject produced inhibition of upper limb flexor tone and lower limb extensor tone ipsilateral to the lateral tilting. Therefore, this opposite effect of tonic labyrinthine reflexes seem to be postural stabilization when the head and/or neck change position (Aiello et al. 1992).

In summary, the vestibular system plays an important role in the locomotor pattern. Deiters' nucleus and the vestibulospinal tract have a facilitatory effect on the motor neurons of the extensor muscles of the lower limbs. In addition, depending on the different types of vestibular perturbation applied, such as electrical stimulation of vestibular receptors, dynamic forward whole-head-and-body tilts, static forward whole-head-and-body tilts and lateral tilting, or the body's orientation in respect to gravity, a facilitatory or an inhibitory effect on the extensor MN of the lower limbs may be produced.

Studies conducted on postural control by linear translations including either a static or dynamic position, have shown, as mentioned before, that the vestibular system plays an important role in the control of posture and locomotion. No study has yet examined the effect of linear perturbations in an anterior-posterior direction during rhythmic movements such as pedalling.

3. METHODOLOGY

3.1 PARTICIPANTS AND SAMPLE SIZE

Initially, the number of participants was determined using SigmaStat 3.11 (SPSS) and the results from Thompson & Bélanger (Thompson and Bélanger 2002). To obtain an H reflex average of 66% with a deviation of 14% of the M_{max} and to obtain a power of 0.8 and an α value of 0.05 a minimum of three subjects must be considered. In order to ensure a small probability of committing an error of type II, it was determined that 10 subjects would participate in this study (Bélanger et al. 2001;Thompson and Bélanger 2002). However, because of technical problems, the H reflex was not included in this study. Moreover, when examining other studies investigating the postural muscle activity response to different perturbations 7 to 10 participants were used in their experiments (Henry et al. 1998;Henry et al. 2001). Hence, for this particular study, a group of ten healthy, young adults who do not have any self-declared neurological or orthopaedic problems were recruited from the university population. In order to participated in this study the subjects had to sign a consent form in accordance with the UQAM ethics committee (see approval in Annexe A).

3.2 PEDALLING CONDITIONS

This study investigated the EMG responses produced during pedalling movements with linear forward and backward translations. Four pedalling conditions were done: a dynamic active (DA), a dynamic passive (DP), a static active (SA), and a static passive (SP) pedalling condition. Before these four conditions were performed, participants carried out a dynamic active pedalling control condition, during which they pedalled for about 5 minutes without any linear translation, to facilitate their pedalling rhythm during the experiment and also to be used as a play back during the DP condition.

In the first condition, the dynamic active pedalling condition, participants pedaled at a frequency of 1 Hz and at a very low resistance. The rate was set with a metronome and the subjects were given feedback to allow them to maintain a constant rate. This condition represents the control condition in which there is voluntary descending inputs and feedback from the moving limbs. In the second condition, the dynamic passive pedalling, movement of the lower limbs were produced by a torque motor controlled by the signal obtained in the previous condition. In this dynamic passive pedalling condition the feedback from the moving limbs is present, but there are no descending inputs. (A torque motor replaces the voluntary control. Note that this input is used to control the pedalling movement and no other action. Furthermore, it cannot truly eliminate the descending inputs completely). In the third condition, the static active pedalling, participants oriented their lower limbs in the pedalling position and had to contract the Soleus muscle to the level observed in the dynamic active pedalling condition. In order to help participants attain and maintain the correct level of contraction, a digital oscilloscope, which provided numerical and graphical information, was placed in front of them. Thus, participants received the descending inputs for the muscle contraction and feedback from the static orientation. Finally, the fourth condition, the static passive, is the same as the previous one, but without contraction of the Soleus muscle. In this last condition there is a static position feedback information will be received, but no descending inputs.

The pedalling cycle was divided into four phases, or quadrants. These angles represent the different positions of the lower limbs during the pedalling cycle similar to the phases during locomotion. Zero degrees (0°), being the top-dead centre, corresponded to the propulsion phase; 180° corresponded to the recovery phase while 90° and 270° corresponded to the transition phases between the other two phases.

The bicycle pedal movements were quantified with an optical encoder that sent its signal to the computer in order to obtain the cycle duration, the stimulation phases, and to control pedalling during passive movements. The applied force on the pedal (perpendicular to the pedal) was quantified using force-sensitive resistors (FSR - Interlink®). They were also used to control the level of contraction of the Soleus muscle during the static active pedalling condition.

3.3 MEASUREMENTS AND STIMULATION

3.3.1 EMG RECORDINGS.

Surface electromyographic (EMG) activity was be recorded from the following muscles: the Soleus (Sol), the Tibialis Anterior (TA), the Vastus Lateralis (VL), and the Biceps Femoris (BF) short head. These four particular muscles were chosen since responses may occur on many levels, and information can be obtained from the flexor and extensor muscles at the ankle and knee joints. The participants' skin over the belly of each muscle was shaved and then cleaned with an abrasive paste and alcohol. The recordings were taken using surface bipolar electrode configuration per muscle. The electrodes were placed parallel to the muscle fibres and 10 mm apart, and for the Sol, recording electrodes were placed along the muscle 4 cm below the point where the two heads of the Gastrocnemius join the Achilles tendon. In addition the impedance of the skin electrodes will be verified and ensured to be below 10 kΩ .

The EMG signals was amplified (Differential Amplifier Grass P511) and filtered at a bandwidth of 10 to 300 Hz. All electrophysiological signals were digitized at 2000 Hz per channel on a Digidata 1200/Axoscope® acquisition system. The EMG from the Soleus was also displayed on a digital oscilloscope (Fluke 50 MHz Scopemeter, model 97).

3.3.2 LINEAR ANTERIOR-POSTERIOR (A-P) TRANLATIONS.

Linear A-P translations affecting mainly the otoliths (because of the type of perturbation) and the semi-circular canals to a lesser degree was applied during the pedalling conditions. The linear A-P translations was produced by an electrical cylinder attached to a special translation table onto which is placed the ergocycle and the seat (figure 1). Forward or backward translations (2.54 cm) of the table was applied at random and when the lower limb was at any of the four phases of the pedalling cycle. Note that the stimulation requires an acceleration greater than 0.06 m/s^2 to activated the otolith receptors (Benson *et al.* 1986). The acceleration was measured by an accelerometer (ICP, model 352C22), that was placed on the forehead with a band attached to the head support of the ergocycle and the signal amplified with Battery Powered Signal Conditioner (ICP, model 480B21).

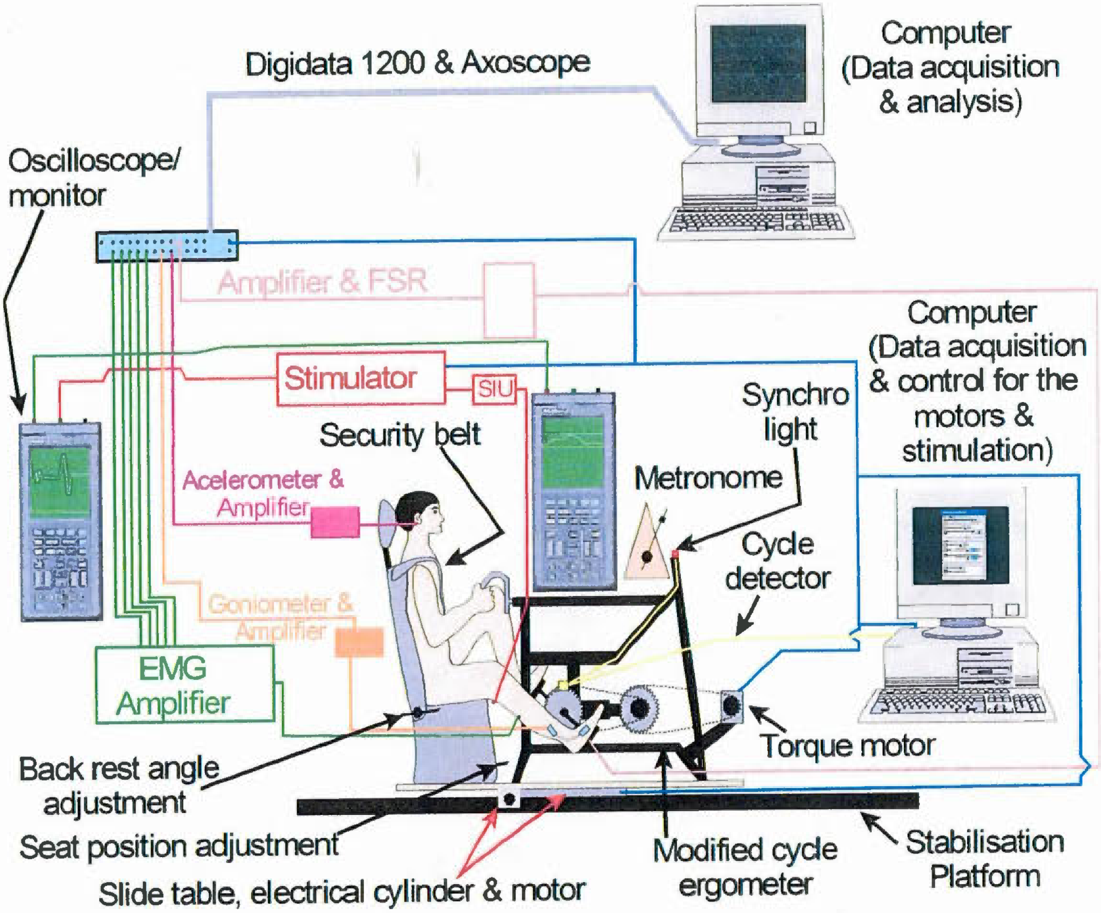

Figure 1: Experiment Set-up

3.4 GENERAL EXPERIMENTAL PROTOCOL

After the measuring equipment was calibrated, the participants was called to the laboratory and was received a clear explanation about the experiment. They were be asked to sign a consent form. Then, the subject was prepared for the surface electromyographic (EMG) with the technique mentioned before.

Participants then asked to sit on the modified cycle ergometer (Figure 1), and an electrogoniometer (EGM) (Penny & Giles®, model M-180) was placed on the lateral side of the ankle joint. An accelerometers was also attached to the forehead. At this point, participants were ready to begin the pedalling conditions at the required frequency. In the passive conditions, participants were asked to relax completely and try not to decelerate or accelerate the pedals. Also the feet were attached to the pedal with Velcro straps to insure that they would not lose contact with the pedals. All pedalling conditions were repeated until a minimum of five linear translations in both directions, backward and forward, were colleted.

To facilitate and speed up the experiment, the order of the conditions will be established as shown in figure 4.

S -1	**S - 2**	**S - 3**	**S - 4**	**S - 5**	**S - 6**	**S - 7**	**S - 8**	**S - 9**	**S - 10**
DA	SP	DA	DA	SP	DA	DA	DA	DA	SP
DP	DA	SA	SP	DA	DP	SP	SA	DP	DA
SA	DP	DP	SA	SA	SP	DP	SP	SA	DP
SP	SA	SP	DP	DP	SA	SA	DP	SP	SA

Figure 2. Order of Experimental Conditions (DA: Dynamic Active DP: Dynamic Passive; SA: Static Active; SP: Static Passive)

3.5 DATA AND STATISTICAL ANALYSES

Muscular responses (20 ms pre - and 380 ms post-translations) for each of the four stimulated phases of the pedalling cycle were averaged together and compared with the EMG signals obtained during the corresponding phases of the control cycles. The control data was obtained from the cycles preceding the translations.

The control and the perturbed EMG activity for each muscle in each condition, were both rectified and normalized to the maximum value of the control cycles during the dynamic active condition. The integrals for each of the phases of the translated cycles were averaged and then compared with the control values. A two-way repeated measures ANOVA was performed for all of the conditions. Student-Newman-Keuls post hoc analyses were used as well to establish where the differences were between the conditions in each phase.

4. RESULTS.

Figure 3 illustrates the EMG pattern of the four muscles recorded during the dynamic active condition (DA). The panel on the left shows that the extensor muscles of the ankle (soleus) and knee (vastus lateralis) both become active before top dead center (0°) and remain active until close to 90°. The flexor muscles (tibialis anterior and biceps femoris), illustrated on the right, showed two bursts of activity, one starting just after bottom dead center (180°) while the other starts near 0°. All changes occurring as a result of A-P translations were compared to this dynamic active condition. The results of the static conditions will be presented first followed by the dynamic ones.

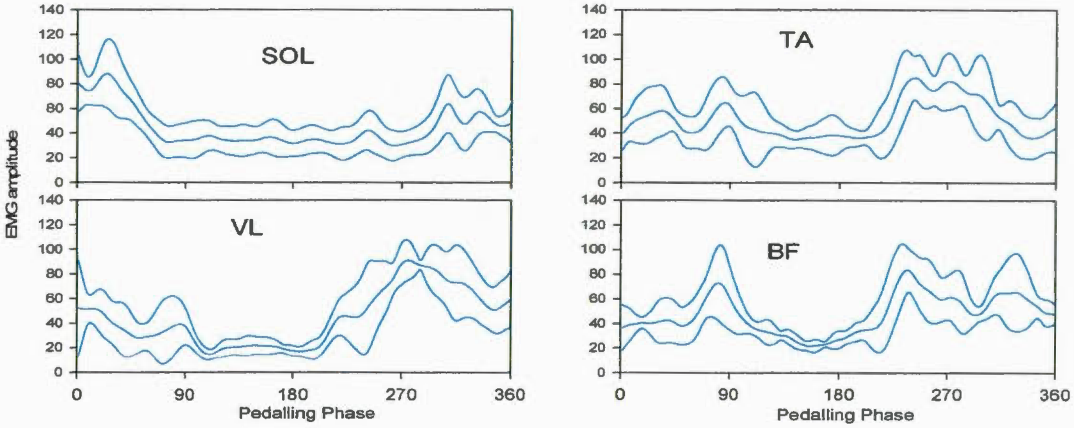

Figure 3. EMG activity of the four tested muscles: Soleus (SOL), Tibialis Anterior (TA), Vastus lateralis (VL), and Biceps femoris (BF) from a single subject. Ordinate shows the EMG amplitude normalized to the maximal value

obtained during dynamic active pedalling and abscissa shows the pedalling phases (0° represents top dead center). Data acquisition was acquired at 2000Hz and filtered at 10 Hz. The traces represent the mean (middle trace) and the standard deviations.

4.1 STATIC CONDITIONS

During the static passive condition (SP), there was no EMG activity since the limbs are simply positioned at one of the four phases (angles). Following the anterior translations (AT), there were clear modulatory responses in the soleus in all phases (figure 4). The Sol muscle also showed modulatory responses in all phases following posterior translations (PT) (figure 5). It is quite clear from figure 6 that the response was modulated following both anterior and posterior translations. On the other hand, when AT and PT Sol responses were compared, no significant differences were observed during the static passive condition. However, the amplitude for the Sol response at 270° tended to be greater in the PT than in AT conditions.

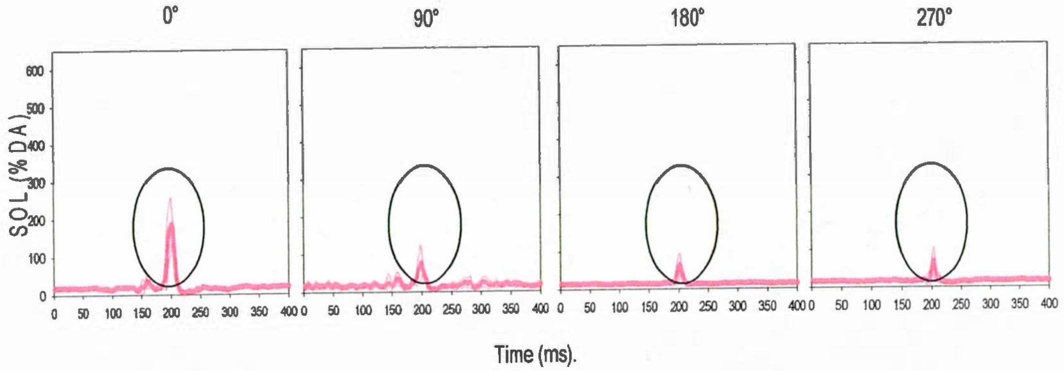

Figure 4. Soleus responses in the static passive condition following A-T for subject 8. Linear envelope (filtered at 100 Hz) EMG data (mean and the standard deviations). Ovals around the traces indicate significant excitatory response in all phases of the pedalling cycle.

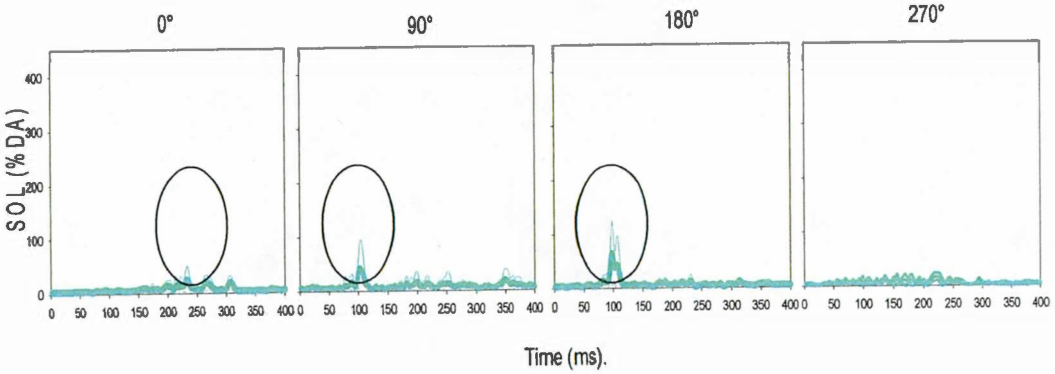

Figure 5. Soleus responses in the static passive condition following P-T for subject 8. see the legend in figure 4.

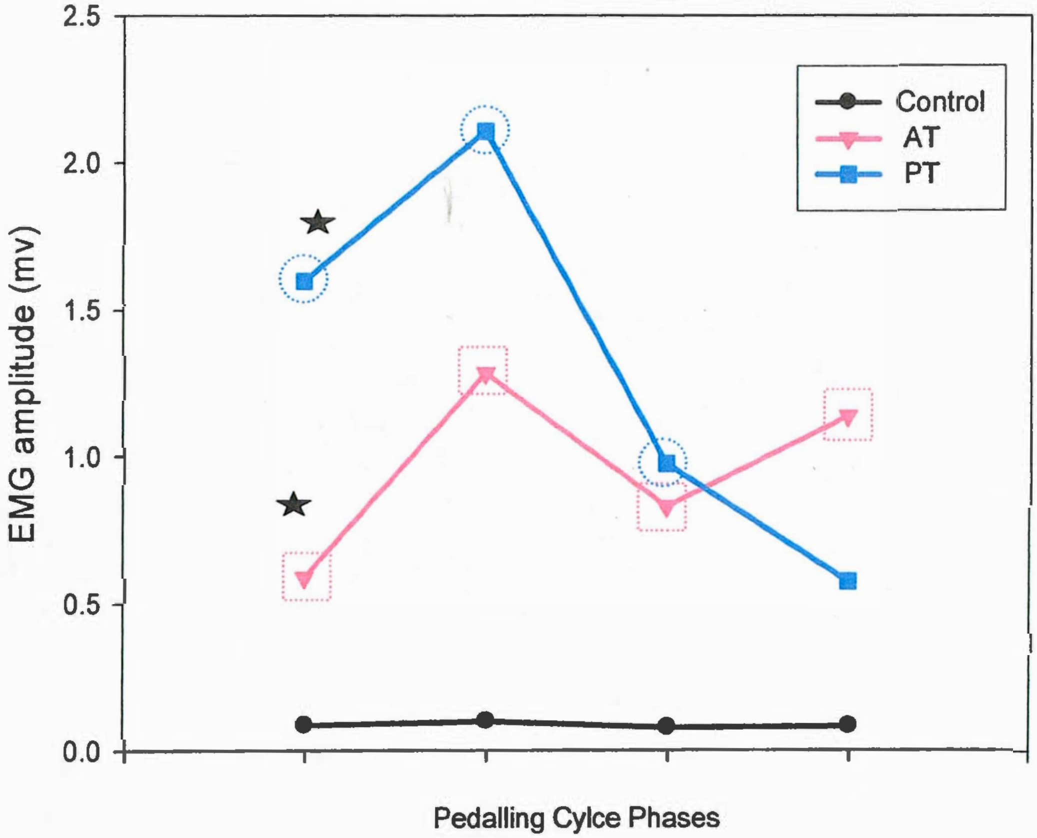

Figure 6. Soleus responses in the Static Passive Condition for all subjects. Circles and squares around line symbols indicate significant differences ($p<0.05$) from control value for the anterior and posterior translations respectively. The stars indicate significant differences between the A-P translations.

Interestingly, during the static conditions, the Sol response in most of the subjects and at the different pedalling phases followed the EMG pattern observed during the DA control condition, that is, highest in the propulsion phase (0°) and lowest in the recovery phase (180°) (see figure 3). No significant changes were seen in the other muscles during the static passive conditions.

It is important to note that during these static conditions the latency of the muscle response appeared to be different between AT and PT. The latencies were around 150 to 200 ms in the forward translations, while they were about 100 ms in the backward translations. However, these differences were only significant in two of the subjects.

Significant responses were observed in both the soleus and vastus lateralis muscles during the static active (SA) conditions. An anterior translation produced modulatory responses in the Sol (Figure 7) and VL (Figure 8) muscles. For the Sol, there was a response in all 4 phases (0°, 90°, 180°, 270°). Interestingly, the response always followed the same pattern as the EMG activity recorded during the dynamic active control condition. Similarly, the VL responded with a significant increase in the muscle activity for all phases. The level of response followed a pattern similar to the EMG activity seen during the DA control condition. No significant responses were found in the flexor muscles.

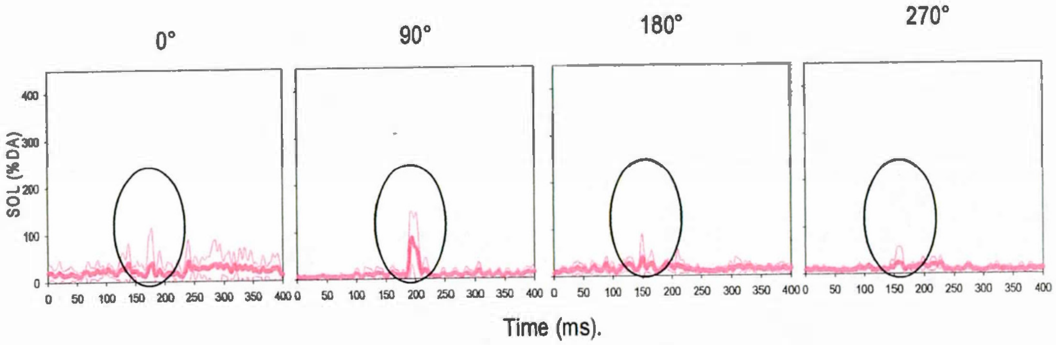

Figure 7. Soleus responses in the Static Active Condition following A-T for subject 10. See legend for figure 4.

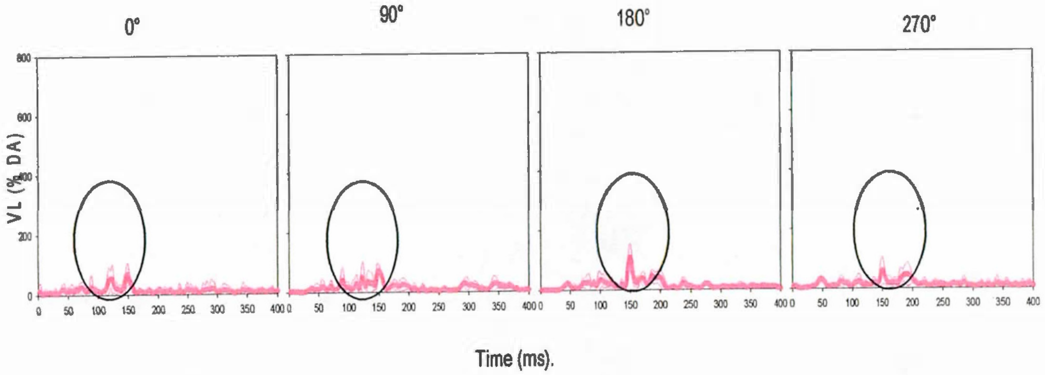

Figure 8. Vastus Lateralis responses in the Static Active Condition following A -T for subject 10. See legend for figure 4.

The posterior translations also resulted in modulatory responses in the Sol (Figure 9) and VL (Figure 10). However, Sol, responses were observed only at 0°, 90° and 270°. For the VL, significant responses were seen at 0°, 90° and 180°. There was also a small response at 270°, but it was not significant.

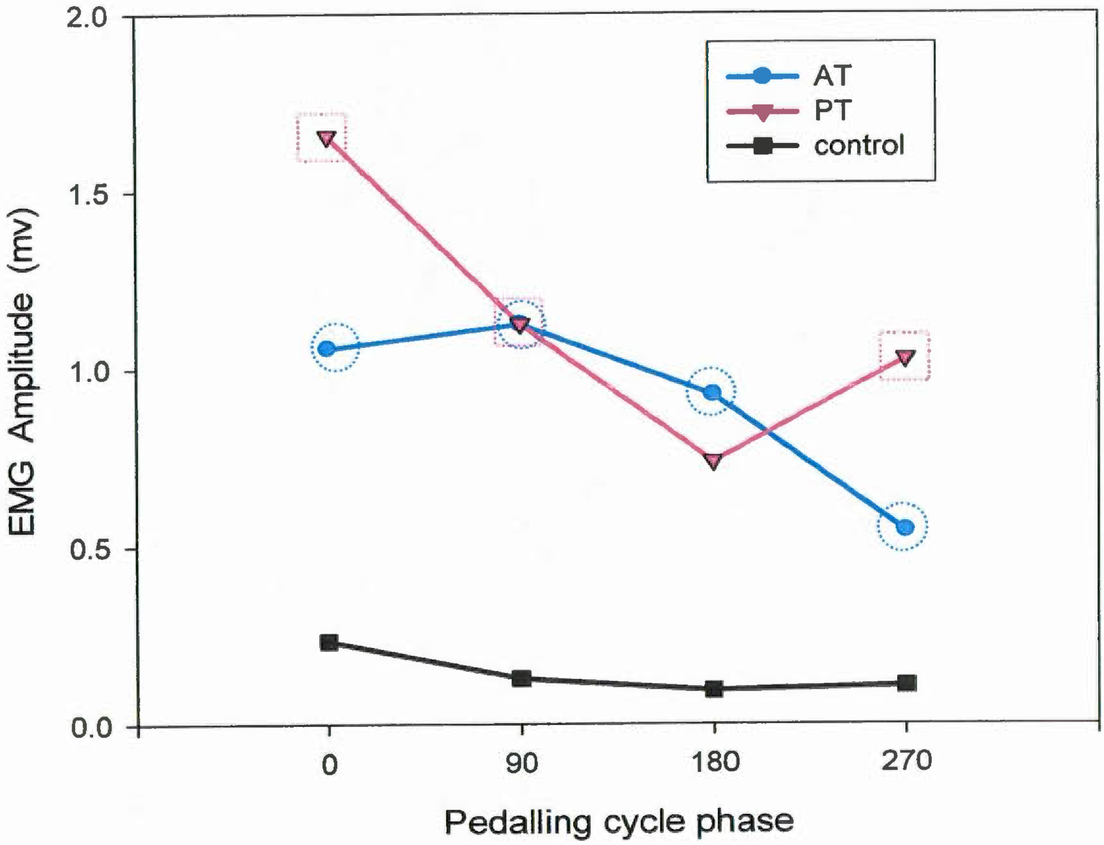

Figure 9. Soleus responses in the Static Active Condition. See legend for figure 6

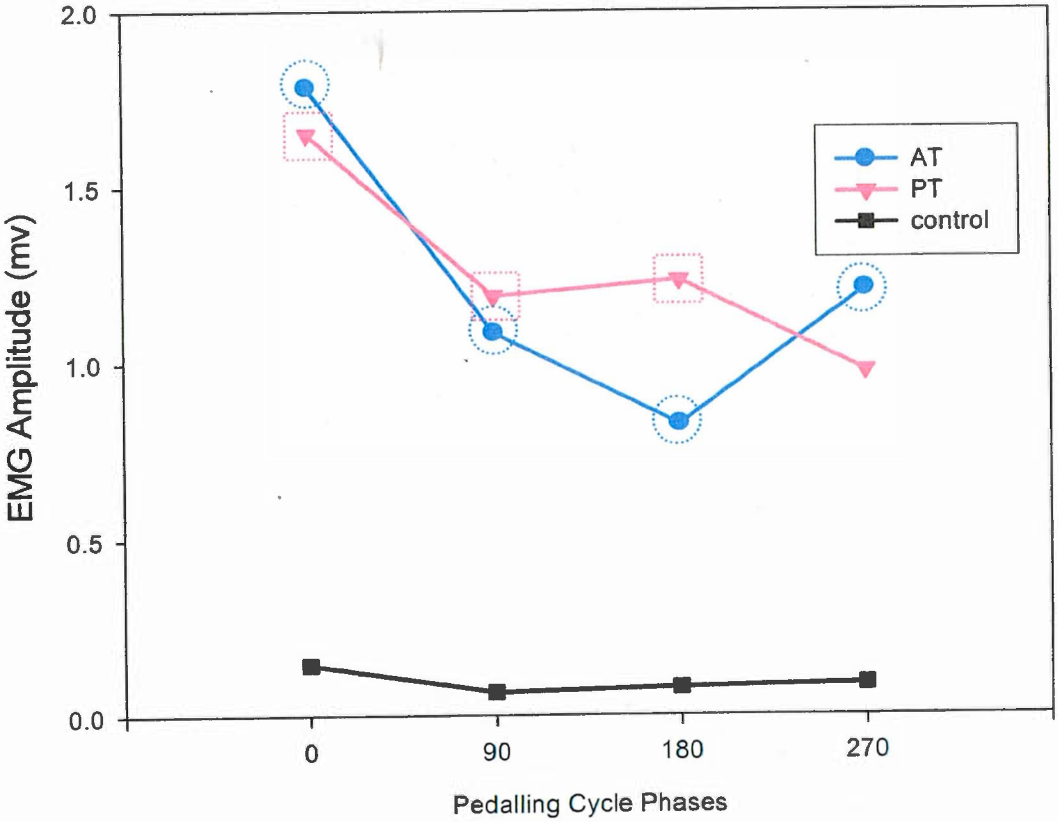

Figure 10. Vastus Lateralis responses in the Static Active Condition. See legend for figure 6.

4.2 DYNAMIC CONDITIONS

Figure 11 shows data of the EMG activity of one of the subjects. We can clearly appreciate the facilitation in the Soleus following AT. On the other hand, when the data for all the subjects was pooled together, there was no significant response to either the AT or PT during the dynamic conditions. This is true for both the active or passive pedalling conditions. On the other hand, there was a tendency for the Sol to show excitatory effects following AT, particularly at 0°, 90° and 270°.

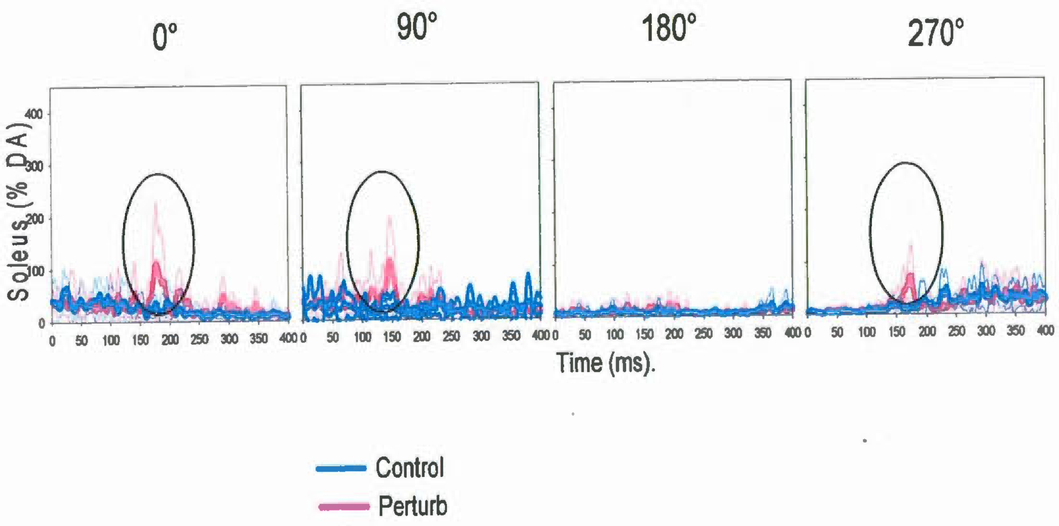

Figure 11. Soleus responses in the dynamic active condition following AT for subject 6. The mean (bold line) and the standard deviations (thin lines) of the control (blue) and the translated (red) cycles are shown on each panel. The data include 20ms before AT to 400ms after the translation. Ovals

indicate an excitatory response at 0°, 90°and 270°.Also can be observe that the responses manly occur close to 150ms after the translation.

As mentioned above, no significant change was found in the EMG activity of the muscles for the PT during the DA condition. Although, as for the AT, the Soleus seems to have an excitatory response at 0°and at 270° as shown for one subject in Figure 12.

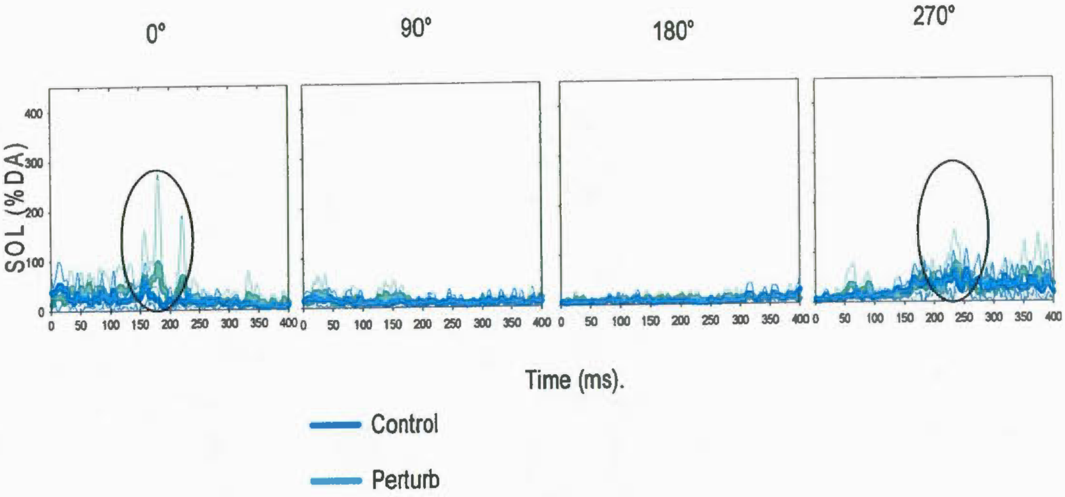

Figure 12. Soleus responses in the dynamic active condition following PT for subject 6. The mean (bold line) and the standard deviations (thin lines) of the control (blue) and the translated (green) cycles are shown on each panel. The data includes 20ms before AT to 400ms after the translation. Ovals indicate an excitatory response at 0° and 270°.

Although the muscles were slightly active during the DP condition, there was no response to either AT or PT. Many of the subjects were not able to relax completely. However this activity did not match with the pattern or the level of the EMG activity recorded from the dynamic active control condition.

Figure 12 shows the effect of the translations on the cycle durations. The control (prior to the translation - 1) cycle was compared with the translated (2) one and the two cycles (1 and 2) following translation. In general, there was no effect of the translations on the duration of the pedalling cycles, as no significant differences were found after the A-P translation was applied at the four different pedalling phases. On the other hand, the first post-translated cycle was shortened while the second post-translated one was lengthened when the translation occurred at the 0° phase for A-T. Also, the first post-translated cycle tended to be shorter for 90° and for 180°, although it was not significant.

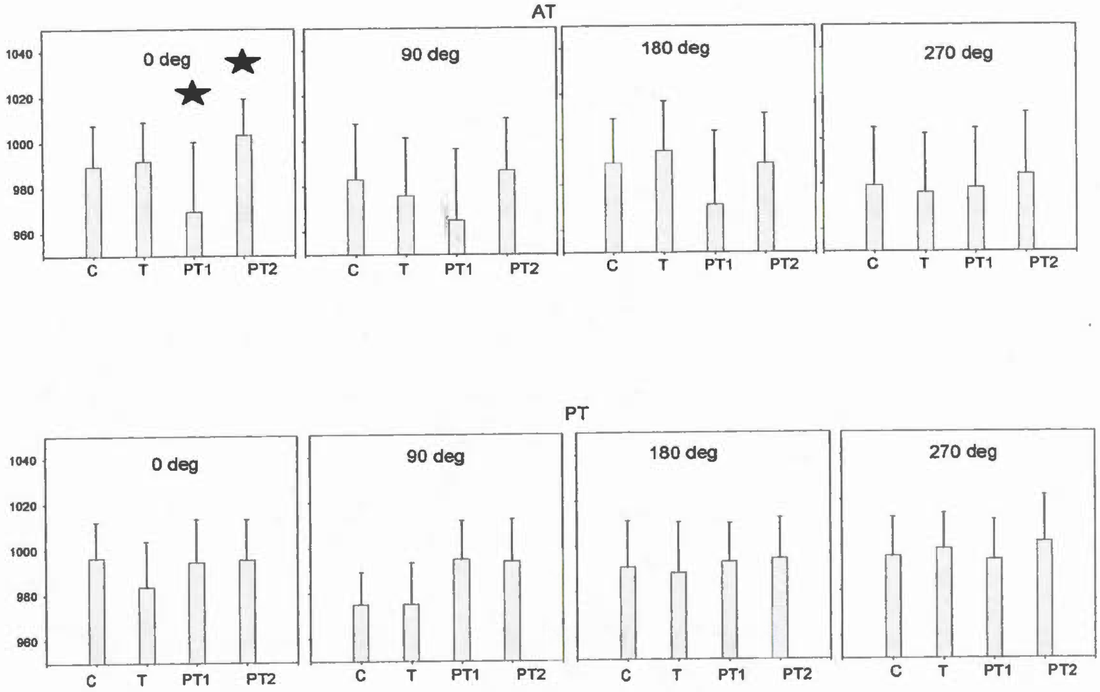

Figure 13. Effects of the translations on the pedaling cycle duration at four different phases. The height of the bars indicates the mean duration (in ms plus standard deviations) of the control (before translation – C), the translated (T), the first post translated (PT1) and the second post translated (PT2) cycles. Stars indicate the significant differences (p<0.050) from the control value.

5. DISCUSSION.

5.1 STATIC CONDITIONS

The results presented above showed that rapid linear translations can produce responses that modulate the activity of the muscles according to the phase of the pedalling cycle during static conditions (i.e., different limb positions). These modulations seem to be independent of the direction of the translation.

For the static passive condition, only one of the tested muscles (Sol) showed responses that were modulated. The modulation was observed in the four different phases of the pedalling cycle, but in terms of amplitude, the major effect was observed at 0° and 90° of the pedalling cycle. Those correspond to the propulsion phase and the end of the propulsion phase, respectively. Hence, one could say that the effect of the translation is phase dependent. This phase dependency has also been observed with other types of perturbations during locomotion .

It is important to note that our study cannot be compared completely to several prior studies about postural control because our subjects were sitting with trunk support, and lower limbs oriented in a pedalling position. This creates a stable condition in terms of balance, and the movement is constrained by the pedal motion. In contrast, in the previous studies, the standing position, which functions as an inverted pendulum, was much more unstable and thus resulted in greater muscular response when translated.

However, Inglis et al. (1995) have shown that if the support surface is translated after a bout of galvanic vestibular stimulation, the postural responses of the plantar flexor muscles are altered. The fact that only the soleus responded during the static passive condition may indicate simple extensor response. Inglis et al. (1995) suggested that, these Sol responses may be used to stabilize the ankle joint in order to hold the position of the subject during the experiment.

Our results show that during the static passive condition, the response in the soleus muscle was independent of the direction of the translation. This is in contrast to previous studies that have described that balance corrections are sensitive to perturbation direction (Horak and Nashner 1986;Hughey and Fung 2005). This difference may be explained by the fact that in our experiment this subject's head and trunk was stabilized, hence less movement was possible in either direction.

In addition, the muscle that responded to the anterior translation in the static passive condition, the sol, does not correspond with that of previous studies on multidirectional movable platform (Henry et al. 1998;Hughey and Fung 2005), where the EMG activity to the anterior translation in the thigh and leg muscles was mainly the vastus medialis, adductor longus, semitendinosus, and tibialis anterior; whereas the soleus responded to a diagonal-posterior translation. Once more, it is important to note that because of the subject's position during the experiments and the pedalling phases we tested, our study can only be compared with standing studies in some aspects, in this case with the 0° phase.

Nevertheless, it has been concluded before, that vestibular signals to platform translations have an influence in the postural control; not only to modulate the amplitude of postural responses, but also to give the central nervous system the required feedback referred as sensory reafference, to signal the direction of upright and permit accurate realignment of the body with respect to gravity after a disturbance in stance (Inglis et al. 1995). Thus, we may say that previous studies (Inglis et al. 1995) are consistent with ours results presented above.

For the SA condition, where the subject contracted the Sol muscle to the same level as during the DA condition, we clearly saw a facilitation of the

EMG activity to the anterior translation of the two extensor muscles (Sol and VL) tested during the experiment. This facilitation was observed in the four phases of the pedaling cycle. The activation of these particular muscles to the linear translations can be attributed to an extensor synergy. The synergy we observed is not exactly equivalent to the synergies described in previous studies (Nashner and McCollum 1985;Henry et al. 1998). However, they present some similitude in EMG activity to the anterior translation: there is an activation of the quadriceps.

For the posterior translation, the synergy observed in previous studies showed an activation of the Semimembranosus, Sol, medial gastrocnemius and peroneus longus (Henry et al. 1998), that can be equivalent with our Sol response. However, a synergy organization is not the most appropriate term to explain our results: what we observed was limited to two muscles which can be due to the fact that we recorded just a few muscles, as well as the differences we have in terms of the sitting position of the subjects which may have diminished the response, the phases of the pedalling cycle we tested, in addition to the technical problems we had with some of the EMG.

5.2 DYNAMIC CONDITIONS

Although the results during the dynamic conditions (DA and DP) were not significant, mainly due to small number of responses and variability between those responses, the Sol response to the translations tended to be modulated in a fashion similar to what was observed for the Sol H reflex during pedaling (Brooke et al. 1992;Boorman et al. 1992) and walking (Capaday and Stein 1986). If we compare our results with the ones obtained using H reflex modulation, H reflexes observed during walking and pedalling where one sees variation in magnitude across particular phases of the movement (Capaday and Stein 1986;Crenna and Frigo 1987;Boorman et al. 1992). In these studies the H reflex reached a maximum amplitude when evoked during the power phase (0° and 90°) (Brooke et al. 1992), and the reflexes became progressively smaller as the pedalling cycle advanced just as we observed in our data.

For the anterior translation, the Sol had a tendency to follow changes in the EMG amplitude during the pedalling cycle, more evident for the positions of 0° and 90°, which correspond to the propulsion phase in the pedalling cycle (Brooke et al. 1992;Boorman et al. 1992) or to the stance phase if compared with locomotion (Capaday and Stein 1986;Capaday and Stein 1987). These results also correspond with Orlovsky's studies, where he shows that the vestibular system has an excitatory effect in the α motor neuron that innervates the extensor muscles in the lower limbs during the stance phase (Orlovsky 1972b;Orlovsky 1972c).

Our results showed that the modulatory effect of linear displacements during pedalling movement is phase dependent; the EMG amplitude increases during the propulsion phase of the pedalling cycle and decreases in the recovery phase. This is consistent with the results of a previous study that showed that during locomotion, a phase-dependent modulation take place after vestibular perturbations (galvanic vestibular stimulation) are introduced during the gait cycle (Bent et al. 2004).

The latencies of the responses observed in the present study (around 100 to 150 ms) are consistent with the ones observed by Lacour et al.(1974). The late muscular responses to the linear translations are in the range of latencies that can be attributed to vestibular activation proposed by Nashner in 1976. The earlier responses observed in platform translation studies were the results of the activation of the stretch receptors while the late responses were attributed to the activation of the vestibular system (Nashner 1976;Inglis et al. 1995). The control mechanisms of posture and locomotion are composed by a complex interaction of the central and peripheral information. The somatosensory signals trigger and shape initial postural responses to platform translations, whereas vestibular signals are more involved in late components of the automatic postural responses(Nashner 1976;Inglis et al. 1995).

The vestibular system as mentioned before has an important function on the postural control and locomotion: triggering the onset of automatic postural responses (Horak et al. 1994); also depending on the disturbance velocity, vestibular signals modulate the amplitude of automatic postural responses to the same magnitude of the postural disturbance (Horak et al. 1990); finally, the vestibular system may play a critical role in providing the sensory reafference during postural movements that would permit the CNS to determine whether and automatic postural response is appropriate and effective (Von Holst and Mittelstaedt 1973).

As for, in terms of cycle duration, no significant differences were found after the A-P translation was applied. When the A-T was given in the propulsion phase, which correspond to the stance phase if compared with walking, the subject tended to accelerate, not during the actual perturb cycle, but for the next cycle, and slow down for the very following cycle. Whereas when the A-P translation was given in the recovery phase of the pedalling cycle no changes in the duration were found. The change in the cycle duration following AT translation occurred despite the fact that the subjects were asked to maintain their cycle durations at 1 s (pedalling at 1 Hz) and were accompanied by a metronome. These results are similar to previous studies by Forssberg in 1975, where it was shown how the unexpected perturbations during walking change the cycle duration in cats, particularly if stimulus was applied during the late portion of the stance phase, the cycle duration could be shorted by approximately 200 ms., and if the stimulus was given in the swing phase the cycle remained unchanged.

6. CONCLUSIONS

The influence of the vestibular system in posture and locomotion has been made clearer. In static conditions, we showed how the lower limb extensor muscles, Sol and VL, are modulated during the phases of the pedalling cycle following linear translations. On the other hand, the responses were independent of the translation directions.

Despite the fact that there was a small number of trials during dynamic conditions, our results still show some phase and tasks modulations in the EMG responses following anterior and posterior translations. Moreover, according to the latencies of response in the EMG, we suggest that vestibular influences (A-P translations) do have the modulatory late effect that influences the muscle activation in dynamic and static. However, further work will be required to confirm the results presented here and reinforce our suggested conclusions.

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ANNEXE A

UNIVERSITÉ DU QUÉBEC À MONTRÉAL FORMULE DE CONSENTEMENT

J'accepte d'apporter volontairement ma collaboration au projet de recherche intitulé, Effets de perturbations vestibulaires sur le réflexe H et les ajustements posturaux, mené sous la direction de professeur Marc Bélanger, PhD à l'Université du Québec à Montréal. Je suis au courant de la nature de cette recherche, qui m'a été présentée oralement, dont le but poursuivi est de façon générale l'avancement de la science et plus particulièrement: d'examiner la modification de mouvements de pédalage suite à des perturbations de l'équilibre. Ces perturbations pourraient être comparées à des freinages rapides ou des accélérations du corps et de la tête lorsqu'une personne est debout dans un autobus ou un train de métro.

Ma participation à titre de sujet impliquera:
Que je m'assoie sur un ergocycle modifié (bicyclette stationnaire avec siège derrière les pédales) et que je pédale à une vitesse de 60 tours par minute. J'aurai des électrodes d'enregistrement fixées à la surface de la peau au-dessus de certains muscles du membre inférieur afin de mesurer leur activité durant les mouvements. Je recevrai des légères perturbations derrière la jambe droite (stimulation électrique pour étudier les réflexes musculaires) une fois à tous les 6-9 tours de pédale. De plus je serrai soumis à des translations (mouvements linéaires) vers l'avant ou vers l'arrière de la plate-forme sur laquelle se situe l'ergocycle (similaire à un arrêt ou un départ rapide d'un train de métro ou d'un autobus). Dans une autre partie de l'expérience, je relaxerai pendant qu'un moteur dynamométrique déplacera mes membres en mouvements de pédalage alors que je recevrai les deux types de perturbations déjà mentionnées. Dans une troisième partie de l'expérience, mes membres inférieurs seront placés en positions de pédalage et j'aurai à contracter mes muscles comme si je pédalais, et je recevrai les deux types de perturbations déjà mentionnées. Dans une dernière phase du projet, mes membres inférieurs seront placés en positions de pédalage, j'aurai à relaxer et je recevrai les deux types de perturbations déjà mentionnées.

Conséquemment, toutes les précautions sont prises pour minimiser au maximum les inconvénients et les risques pour ma personne. J'accepte de participer à cette recherche étant cependant entendu que je pourrai me retirer, en tout temps, sans préjudice et pour des motifs dont je serai le seul juge.

Il est entendu que, si après le début de ma collaboration à cette recherche, les responsables prévoient que sa poursuite présente des risques pour mon bien-être, ils devront m'en informer et m'inviter à me retirer.

Je reconnais également que les responsables pourront mettre fin à ma collaboration en tout temps quand ils le jugeront nécessaire.

Il est convenu que les renseignements recueillis à mon sujet dans le cadre de cette étude pourront être utilisés par les responsables aux seules fins énoncées dans la présente recherche et, à la condition que les éléments qui pourraient être de nature confidentielle ne soient pas divulgués dans le public d'une façon telle que l'on puisse m'identifier.

Cette recherche a reçu l'approbation du Comité institutionnel d'éthique de la recherche chez l'humain (CIÉR) de l'UQAM (secrétariat du Comité : service de la recherche et de la création, Université du Québec à Montréal, C.P. 8888, succursale Centre-ville, Montréal, QC, H3C 3P8 – Téléphone : 514-987-3000 poste 7753). Toute question sur le projet, plainte ou commentaire peut être adressé au chercheur. Pour toute question sur les responsabilités des chercheures ou, dans l'éventualité où la plainte ne peut leur être adressé directement, vous pouvez faire valoir votre situation auprès du CIÉR.

Signé à Montréal en duplicata, ce

____
(Participant)

____
(Responsable)

____
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