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The gait initiation process in unilateral lower-limb amputees when stepping up and stepping down to a new level

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Abstract

Background. Unilateral lower-limb amputees lead with their intact limb when stepping up and with their prosthesis when stepping down; the gait initiation process for the different stepping directions has not previously been investigated.

Methods. Ten unilateral amputees (5 transfemoral and 5 transtibial) and 8 able-bodied controls performed single steps up and single steps down to a new level (73 and 219 mm). Duration, a-p and m-l centre of mass and centre of pressure peak displacements and centre of mass peak velocity of the anticipatory postural adjustment and step execution phase were evaluated for each stepping direction by analysing data collected using a Vicon 3D motion analysis system.

Findings. There were significant differences (in the phase duration, peak a-p and m-l centre of pressure displacement and peak a-p and m-l centre of mass velocity at heel-off and at foot-contact) between both amputee sub-groups and controls ($P < 0.05$), but not between amputee sub-groups. These group differences were mainly a result of amputees adopting a different gait initiation strategy for each stepping direction.

Interpretation. Findings indicate the gait initiation process utilised by lower-limb amputees was dependent on the direction of stepping and more particularly by which limb the amputee led with; this suggests that the balance and postural control of gait initiation is not governed by a fixed motor program, and thus that becoming an amputee will require time and training to develop alternative neuromuscular control and coordination strategies. These findings should be considered when developing training/rehabilitation programs.

Keywords: Lower-limb amputation; Amputee; Gait initiation; Stepping; Locomotion; Centre of mass; Centre of pressure

1. Introduction

The transition from upright standing to stepping or walking is a common locomotor task. Such transitions, commonly referred to as gait initiations, involve complex and synergist neuromuscular control and coordination (Dichgans and Diener, 1989; Paulus et al., 1984). In attempting to understand the balance and postural control strategies used in executing a gait initiation, previous research has determined the relationship between the horizontal trajectories of the body centre of mass (CoM) and the point of application of the ground reaction force vector (the so-called centre of pressure, CoP). The gait initiation process in healthy able-bodied individuals is characterised by stereotypical displacements of the CoM and CoP that result from a consistent pattern of lower limb muscle activity. For example, during the early part of initiation, from movement initiation up

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to swing limb heel-off (the so-called period of anticipatory postural adjustment, Gélat and Brenière, 2000), ankle plantar- and dorsi-flexor activity effects a backward and towards the intended swing limb displacement of the CoP, and an accompanying forward and towards the intended stance limb displacement of the CoM (Brenière et al., 1981; Crenna and Frigo, 1991; Elble et al., 1994; Jian et al., 1993). During the subsequent step execution phase (from swing limb heel-off up to swing limb foot-contact, Gélat and Brenière, 2000), swing and stance limb hip abductor muscle activity cause the CoP to move rapidly across to the heel region of the stance limb, while the CoM continues to move forwards (Jian et al., 1993). Following swing limb toe-off, stance limb ankle plantar–flexor activity helps control the forward progression of the CoP beneath the stance foot (Jian et al., 1993). However, while much is known about the gait initiation process used by able-bodied individuals, there is a paucity of information regarding how amputees initiate gait, particularly so when stepping to a new level. The present study was conducted to address this lack of knowledge.

Muscular activity of the lower limbs plays an important role in controlling the displacement trajectories of the CoM and CoP during the gait initiation process. Thus it follows that, because feedback originating from cutaneous receptors within the foot and leg is only present unilaterally (Geurts et al., 1992; Isakov et al., 1992), or at best is available via re-mapped receptors within the stump (Schwenkreis et al., 2003), individuals with a unilateral lower limb amputation will need to adopt alternative, or new, neuromuscular control and coordination strategies.

It has been reported that both transtibial and transfemoral amputees take significantly longer to load their stance limb when initiating gait leading with their intact limb compared to when leading with their prosthetic limb (Michel and Do, 2002; Rossi et al., 1995; Tokuno et al., 2003). This temporal difference was suggested to be a strategy aimed at counteracting the stability and propulsion limitations of the prosthetic (stance) limb (Michel and Do, 2002; Rossi et al., 1995; Tokuno et al., 2003). In two of these studies the horizontal trajectory of the CoP was found to be similar to that seen in able-bodied controls, regardless of the limb with which the amputee subjects led with (Michel and Do, 2002; Rossi et al., 1995). Conversely, the findings of Tokuno et al. (2003) indicated that, while the horizontal trajectory of the CoP during gait initiation when leading with the prosthetic limb was similar to that seen in able-bodied controls, when leading with the intact limb the lateral displacement of the CoP, from its early position towards the intended swing limb back towards the stance limb, also tended to shift anteriorly so that, rather than be located beneath the heel region of the stance foot at swing limb toe-off, it became located beneath the mid-foot or metatarsals head region (Tokuno et al., 2003). These findings indicate that the choice of lead limb will affect the temporal aspects of gait initiation in unilateral lower-limb amputees, but it is unclear the influence such a choice has on the balance and postural control adaptations adopted.

The gait initiation process in unilateral amputees when performing a single step up to a new level (leading with their intact limb) has also been investigated (Jones, 2004). Findings indicated that the initial displacement of the CoP towards the intended swing limb had greater posterior displacement and less lateral displacement in amputee subjects compared to able-bodied controls. In the subsequent step execution phase, the lateral displacement of the CoP back towards the stance limb, tended to move more posteriorly towards the heel region in able-bodied subjects, whereas in amputees it tended to move anteriorly towards the mid-foot region of the stance foot. It was suggested that this adaptation ensured the CoP was kept anterior of the knee joint centre, thereby ensuring the ground reaction force vector helped keep the knee of the prosthetic limb fully extended during the period when body weight was being supported solely by this limb (Jones, 2004).

Given that unilateral lower-limb amputees are taught, during rehabilitation and prosthetic training, to lead with their intact limb when stepping up to a new level, and with their prosthetic limb when stepping down to a new level, amputees may employ a different gait initiation process for each direction of stepping. The aim of the present study was to determine the balance and postural control adaptations adopted by unilateral lower-limb amputees when stepping up and when stepping down to a new level.

2. Methods

2.1. Subjects

Ten male unilateral lower-limb amputees (5 transfemoral and 5 transtibial) and 8 able-bodied controls (subject characteristics are listed in Table 1) participated in the study. All subjects self-reported they were currently moderately active (undertaking exercise bouts such as walking to and from local shops, gardening and engaging in household chores on a daily basis). Details of the prosthetic limb and socket used by each amputee subject are shown in Table 2. The study was performed in accordance with the Declaration of Helsinki and ethical approval for the study was obtained from the University of Bradford Research Strategy Committee. All subjects gave written informed consent to participate in the study. Amputee or able-body individuals with orthopaedic and/or neurological problems or diseases known to affect equilibrium (other than that of their primary pathology, in the case of the amputees) were excluded from the study.