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Control of trunk motion following sudden stop perturbations during cart pushing

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ABSTRACT

External perturbations during pushing tasks have been suggested to be a risk factor for low-back symptoms. An experiment was designed to investigate whether self-induced and externally induced sudden stops while pushing a high inertia cart influence trunk motions, and how flexor and extensor muscles counteract these perturbations. Twelve healthy male participants pushed a 200 kg cart at shoulder height and hip height. Pushing while walking was compared to situations in which participants had to stop the cart suddenly (self-induced stop) or in which the wheels of the cart were unexpectedly blocked (externally induced stop). For the perturbed conditions, the peak values and the maximum changes from the reference condition (pushing while walking) of the external moment at L5/S1, trunk inclination and electromyographic amplitudes of trunk muscles were determined. In the self-induced stop, a voluntary trunk extension occurred. Initial responses in both stops consisted of flexor and extensor muscle cocontraction. In self-induced stops this was followed by sustained extensor activity. In the externally induced stops, an external extension moment caused a decrease in trunk inclination. The opposite directions of the internal moment and trunk motion in the externally induced stop while pushing at shoulder height may indicate insufficient active control of trunk posture. Consequently, sudden blocking of the wheels in pushing at shoulder height may put the low back at risk of mechanical injury.

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1. Introduction

Pushing has been associated with the risk of low-back pain (Damkot et al., 1984; Harber et al., 1987; Hoozemans, 2001; Plouvier et al., 2008). This is remarkable since in pushing, joint moments around the lumbar spine are low (Hoozemans et al., 2004). However, these low moments probably coincide with a relatively low trunk stiffness (Stokes et al., 2000; Chiang and Potvin, 2001), which may put the spine at risk of mechanical injury when trunk perturbations occur (Cholewicki and McGill, 1996), especially given the high inertia of objects handled in industrial pushing tasks (Chaffin et al., 1999; Nussbaum et al., 2000).

When pushing a cart, perturbations of the trunk may occur because of sudden stops. One may, for example, be required to suddenly stop the cart to avoid a collision. The high inertia of the transported object may in this case impose a sudden, yet self-induced, flexion perturbation of the trunk similar to that when lifting an unexpectedly heavy object (van der Burg et al., 2000). Alternatively, sudden stops may occur due to an external event, for example when an obstacle blocks the wheels. In contrast to the self-induced stop, this may impose an external trunk extension moment due to high reaction forces at the hands. Both situations may perturb trunk movement, which could be a cause of injury.

When experiencing unpredictable continuous perturbations during pushing while walking (Lee et al., 2010) and lifting (van DieenDieën et al., 2003), participants respond by stiffening the trunk using cocontraction. The objective of the present study was to investigate how trunk motion and trunk muscle activity are controlled in relation to unexpected sudden stops during pushing. We hypothesized that both types of sudden stops (self-induced and externally induced) could lead to uncontrolled trunk motions, i.e. an increase in trunk inclination due to an external flexion moment during self-induced stops and a decrease in trunk inclination due to an external extension moment during externally induced stops. Additionally, we hypothesized that trunk inclination would be more affected when sudden stops occur during pushing at shoulder height than at hip height. As higher trunk moments and hence higher muscle activity would be present prior to the perturbation when pushing at hip height (Hoozemans et al., 2007). Furthermore, we hypothesized that trunk flexor and extensor muscles would cocontract in response to perturbations in both types of sudden stops.

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2. Methods

Twelve healthy male volunteers (age 30.2 (SD 5.4) years, height 1.86 m (SD 0.06 m) and weight 79.4 kg (SD 8.1 kg)) participated in the experiment after signing an informed consent. Participants reported no history of low-back pain or other musculoskeletal disorders within the past 12 months. The ethics committee of the Faculty of Human Movement Sciences approved the experiment.

2.1. Procedure

Prior to start the experimental pushing activities, participants performed a series of contractions meant to elicit the maximum isometric voluntary contractions (MVC) of each of the trunk muscles studied (McGill, 1991). Then, participants familiarized themselves with the task of pushing a cart for about 5 min. The four-wheeled cart (height 1.6 m, depth 0.8 m, width 0.64 m) weighed 200 kg and had hard rubber wheels, (0.028 m wide, diameter 0.124 m). The two wheels nearest to the subject could swivel. Force transducers were attached to the two handles, at the subject's shoulder height (acromion angle) or hip height (upper border of greater trochanter). Participants pushed the cart while walking over a 5 m distance at a self-selected speed, which was considered as the reference trial. For the perturbation conditions, the participants pushed the cart at their self-selected speed, but in case of the self-induced stopping conditions an auditory stop cue, played at a constant volume during the experiment by a computer, was given at mid-stance phase of the right foot after walking over a 2.5 m distance. Participants were instructed to stop the cart as fast as possible after the cue. For the externally induced stop, the cart was caused to bump into an obstacle, which was a metal bar (length 63 cm, height 2.8 cm, width 7 cm) attached to the cart just in front of the front wheels, which was released by an electromagnet at mid-stance of the right foot (Fig. 1). To avoid the participants becoming aware of the perturbation conditions, several reference trials were performed before each perturbed condition. The sequence of the tasks, i.e. two perturbation conditions (self-induced stop and externally induced stop) at two pushing heights (shoulder and hip heights), was randomized.

2.2. Data collection and analysis

Electromyograms (EMG) were recorded using disposable Ag/AgCl surface-electrodes (Blue Sensor; lead-off area 1.0 cm^2, inter-electrode distance 2.5 cm). After abrasion and cleaning with alcohol, electrodes were bilaterally attached over internal oblique (3 cm medial to the anterior superior iliac spine; ASIS), external oblique (halfway the axial line between the 10th rib and the ASIS), rectus abdominis (3 cm lateral to the umbilicus), multifidus (2 cm lateral to L4/L5), longissimus thoracis pars lumborum (3 cm lateral to L3), iliocostalis lumborum (6 cm lateral to L2), iliocostalis thoracis (6 cm lateral to T11) and longissimus thoracis pars thoracis (3 cm lateral to T10). EMG signals were band-pass filtered (10–400 Hz), amplified (20 times, Porti-17^{TM}, TMS, Enschede, The Netherlands; input impedance $> 10^{12}\ \Omega$, common mode rejection ratio > 90 dB) and stored on disk (sample rate 1000 samples/s; 22 bits). ECG contamination was identified by means of independent component analysis and removed from the signals (Lee et al., 2010). Subsequently, EMG signals were high-pass filtered at 20 Hz and band-stop filtered at 50 Hz and finally full-wave rectified and low-pass filtered at 2 Hz (2nd order Butterworth). The signals of the MVC trials were processed using the same steps and the maximal values were used to normalize the EMG signals. The sample rate was off-line reduced to 50 samples/s using a running average. After normalization with the MVC values, bilateral internal oblique, external oblique and rectus abdominis EMG amplitudes were averaged to represent abdominal muscle activity and multifidus, longissimus thoracis pars lumborum, iliocostalis lumborum, iliocostalis thoracis and longissimus thoracis pars thoracis were averaged to represent back muscle activity during the whole trial time series.

Exerted hand forces and kinematic data of LED cluster markers on the upper body segments were collected by 3D force transducers (SRMC3A series, Advanced Mechanical Technology, Inc., USA) and an Optotrak system (Northern Digital, Waterloo ON, Canada), respectively. Force data were stored at 1000 samples/s and then reduced to 50 samples/s using a running average. Clusters of three LED markers were attached to a 50 mm equilateral triangle metal plate on a double hinge joint. Clusters were placed on the pelvis, thorax, bilateral upper arms and forearms and additional markers were placed at the feet and at the handle of the cart. Marker positions were recorded at 50 samples/s. The external moment at the L5-S1 intervertebral disk was estimated from the reaction forces at the hands and the anthropometry and kinematics of upper body segments (trunk inclination), using an inverse dynamic model (Kingma et al., 1996). Markers on the feet were used to monitor the gait pattern during the trials, detect mid-stance of the right foot on-line for triggering of the auditory stop cue or obstacle release and calculated the self-selected walking speed before stopping cart push.

To study the control of the trunk motion in response to the sudden stops, trunk inclination and external moments at the L5/S1 in the sagittal plane were analyzed for the first second after the cue occurred, the obstacle was released, or after the mid-stance phase of the right foot after walking over a 2.5 m distance in the

Fig. 1. The experimental setup, which the four-wheeled cart instrumented with an electromagnetic device holding an obstacle in front of the front wheels.

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