

## **Control of trunk movement: Perturbations in cart pushing**

Mechanical perturbations challenge trunk stability, which is considered a risk factor for low-back injury. Increased trunk muscle activity causes an increase in trunk stiffness, which enhances the trunk stability and may thus prevent negative effects of mechanical perturbations. However, trunk stiffness is relatively low during low-demand tasks, such as pushing tasks. Pushing carts has therefore been suggested to impose a challenge for trunk muscle control as a system with a relatively low stiffness may have to deal with perturbations induced by an object with high inertia. This might cause uncontrolled trunk motions and inappropriate trunk muscle responses could further increase the risk of low-back injury.

In pushing tasks, handle height is one of ergonomic factors, which determines trunk posture and affects trunk muscle activity, i.e. when pushing at low handle height trunk inclination is larger and trunk muscle activity is higher, which may affect the impact of perturbations. In addition, expectation of an impending perturbation may lead to early initiation of trunk muscle activity, which may also reduce the impact of the perturbations. This thesis focuses on trunk moment perturbations in the sagittal plane and transverse planes in combination with corresponding trunk muscle activity in response to perturbations, which can occur when pushing a cart. The principal objectives of the studies were: (1) to study the effects of predictable perturbations on the control of trunk muscle activity and trunk motion before the actual occurrence of the perturbations, (2) to study the effects of predictable and unpredictable perturbations on the control of trunk muscle activity and trunk motion after the occurrence of the perturbations, and (3) to study the effects of self-generated and externally generated perturbations on trunk motion after the occurrence of the perturbations and, finally, (4) to study differences in trunk muscle control and trunk motion in response to the perturbations when pushing at shoulder height or hip height.

In **chapter 2**, we studied the effects of handle height and the expectation of sudden unloading during the transition of cart movement from static to dynamic friction. Subjects were asked to push a cart with brakes (externally triggered) and without brakes (self-initiated). This sudden drop in contact force at the hands associated with the onset of cart movement is considered as a sudden

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unloading perturbation. Compared to pushing at hip height, lower muscle activity and trunk stiffness at shoulder height before onset resulted in a higher trunk inclination after onset. Before self-initiated cart movement, trunk stiffness and muscle activity were significantly higher than before an externally triggered onset at a comparable pushing force. In conclusion, higher preparatory activation of trunk muscles serves to increase trunk stiffness in anticipation of cart movement and may reduce the impact of the perturbation associated with the onset of cart movement.

Change in contact force at the hands was shown to cause a perturbation of the trunk in the previous chapter. Opposite to the sudden unloading perturbation in cart pushing, sudden loading was studied in **chapter 3**. The objective of this study was to investigate whether different types (self-generated & externally generated) of sudden loading perturbations due to sudden stops while pushing a high inertia cart. Subjects were instructed to stop a cart as fast as possible after an auditory cue (self-induced stop) or the wheels of the cart were unexpectedly blocked (externally induced stop). Initial responses in both stops consisted of flexor and extensor muscle cocontraction. In the self-induced stops, trunk extension coincided with an internal extensor moment, indicating that voluntary trunk extension was observed. 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 loss of control over trunk posture. In conclusion, different types of perturbations in cart pushing induce voluntary (self-generated) and involuntary (externally generated) trunk motions and particularly when pushing at shoulder height externally generated perturbations may put the low back at risk of mechanical injury.

The horizontal component of the hand force in pushing also affects trunk moments in the transverse plane, i.e. the trunk twisting moments around the L5S1 joint. These moments were expected to vary cyclically when pushing while walking and the objective of **chapter 4** was to investigate whether cyclic oblique abdominal muscle activity was associated with cyclic pushing forces when pushing while walking. In addition, we hypothesized that external and unpredictable perturbations would be counteracted by cocontraction of the

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oblique abdominal muscles. Subjects were instructed to push at two target forces in a static standing position, while walking and additionally while walking and pushing against a randomly perturbed target force to simulate the effect of non-constant rolling resistance. A tonic level of oblique abdominal muscle activity (static component of EMG amplitudes) was used to maintain trunk posture in pushing while walking. The additional dynamic activity was associated with the twisting moments, which were actively modulated by the pairs of oblique muscles as in normal gait. In line with the hypothesis, in the perturbed condition, an increased baseline of oblique abdominal muscle activity reflected cocontraction of the antagonistic muscle pairs of trunk rotator muscles, which was associated with an increase in trunk stiffness around the longitudinal axis.

The small asymmetry of the hand reaction forces in pushing while walking studied in *chapter 4* elicited trunk oblique abdominal muscle cocontraction. More asymmetry of the hand forces is expected when steering a cart to make a turn. The objective of **chapter 5** was to investigate effects of the predictability of the perturbation induced by making a turn while pushing. Subjects were instructed to push while making a gradual turn, a sharp turn and an unexpected sharp turn (i.e. making a sharp turn as fast as possible after an auditory cue). An increase of oblique abdominal muscle activity before the gradual and sharp turns indicated that anticipatory activation occurred when a turn was planned, which was however not directionally specific. After a left turn, trunk twisting motion to the right was associated with a twisting moment in the same direction induced by the reaction forces on the left hand and presumably slowed down by an increased stiffness as a consequence of the bilateral oblique abdominal muscle activity. Anticipatory activation was absent in the unexpected sharp turns and bilateral trunk rotator muscle activity increased only after the turn. Trunk rotation to the right was faster than in the planned turns. In conclusion, trunk motion in pushing while turning was initially opposite to the travel direction. Additionally, the predictability of the turn affected the control of this trunk twisting motion. In the unexpected turns, the combination of an uncontrolled twisting motion with delayed muscle activation may increase the potential risk of low-back injury.

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In conclusion, this thesis provides evidences of changes in contact force at the hands in pushing being a perturbation to the trunk that may impose a risk of low-back injury. In cart pushing, externally generated unpredictable perturbations, especially while pushing at shoulder height, induce involuntary trunk motions counteracted by relatively late responses in muscle activity. Prior to expected and self-generated perturbations, anticipatory activity increased trunk stiffness, but did not completely prevent displacements of the trunk. The impact of perturbations in pushing was attenuated by the increase in trunk inclination associated with pushing at hip height. When generalizing the findings of this thesis to other situations, such as a different cart mass, cart speed or population, the responses of trunk muscle activity and motion should be considered with care, as these factors may affect task demands in terms of external moments to the trunk. Previous studies on trunk control mainly addressed unidirectional sudden loading or sudden release perturbations applied directly to the trunk. In functional activities, perturbations may be multidirectional and may be applied either directly at the trunk or at the hands. The studies presented highlighted differences in patterns of trunk muscle activity between artificial perturbations used in previous studies on trunk control and realistic perturbations during functional activities.