Chapter 7

General discussion
Control of trunk posture and movement

The first major finding based on the studies described in this thesis, is that differences in the quality of trunk control between subjects with and without LBP are rather subtle. The difference between groups was most prominent in the spiral tracking task, where tracking errors were significantly larger in LBP patients (chapter 3). Interestingly, in maintaining a self-chosen upright trunk posture with high precision demands in both planes of motion, precision of trunk control was similar in subjects with and without LBP. However, when the precision demands in both planes of motion were low, LBP patients drifted further from the target than healthy individuals (chapter 4). On the seated balancing task, where trunk control was not the explicit aim of the task, but rather a means to achieve a higher goal (to limit movement of the chair), LBP patients showed a much more upright trunk posture coinciding with increased thoraco-lumbar movements, while differences in center of pressure excursions between groups were non-significant (chapter 5).

In chapter 2, we found that healthy individuals regulate precision of trunk posture directionally specific, reducing movement amplitude in the plane where the precision demand was high, while using the available space in the other plane of motion (chapter 2). In a subsequent study, evaluating precision of upright trunk control with square and rectangular target areas in LBP patients and healthy control subjects, no interaction between group and target area was found on precision of trunk control. This implies that similar directionally specific trunk control is found in LBP patients (unpublished data).

Trunk stiffening

The second main finding of this thesis is that no indications for increased trunk stiffness in LBP patients were found in any of our studies. Specifically, no increased antagonistic co-activation or preferential recruitment of local over global muscles was found in LBP patients (chapters 3, 4 and 5). Moreover, surprisingly, in seated balancing LBP patients showed increased rather than reduced thoraco-lumbar movements compared to healthy controls (chapter 5) and they showed reduced rather than increased preferential recruitment of local relative to global muscles. These results imply that LBP patients did not use a trunk stiffening strategy to protect their spine in the tasks performed in our experiments.
In contrast, previous studies have reported muscle activation strategies aimed at trunk stiffening in LBP patients during slow trunk movements [37-38]. Several factors could explain these conflicting findings. First, the availability of visual feedback of trunk angle in our spiral-tracking task (chapter 3) may have facilitated a feedback control strategy rather than a feedforward co-activation strategy. Second, signal-to-noise ratios in trunk muscle EMG were quite low while maintaining an upright posture (chapter 4) and during seated balancing (chapter 5), due to the small lumbar moments involved in these tasks. This may have obscured effects of trunk muscle recruitment derived from EMG data. Third, the large variability within the LBP population could explain the inconsistent findings between studies. The current thesis describes trunk control during different tasks in one group of LBP patients, and we cannot exclude that some characteristics of this group may differ from the LBP groups that participated in the studies where indications for trunk stiffening by co-activation was found [37-38]. Additional analysis of trunk muscle recruitment during the voluntary slow trunk movements in the LBP group where increased stiffness had been found, also revealed large variations within that LBP group, with several patients showing values within the mean ± 1 standard deviation of the healthy control group [126]. Variability between LBP patients could be related to differences in pain attitudes, such as pain related fear [127] and fear avoidance beliefs [128]. Possibly, LBP patients only show a protective trunk stiffening strategy when they experience the task as threatening or when the task provokes pain. The LBP patients in our studies scored quite low (<3 cm) on a 10 cm visual analogue pain scale, and did not report additional pain caused by the experimental tasks. Moreover our tasks were highly self-controlled, so despite their LBP, patients may not have felt the need to use a co-activation strategy, which is metabolically inefficient. Another option could be a lack of statistical power due to the relatively small subject groups. Since no evidence for an effect is not the same as evidence for no effect, studies with larger subject numbers are required to support our findings. With larger subject numbers it may also be interesting to consider subgrouping of LBP patients [129]. A fourth explanation why we did not find increased antagonistic co-activation in LBP patients may be the type of experimental tasks that we used. Both the spiral tracking task (chapter 3) and the static positioning task (chapter 4) required a certain level of precision, which may lead to similar stiffening in healthy controls. Performance on the seated balancing task (chapter 5) may actually worsen by stiffening the trunk [130].
Another important finding is that trunk stiffening by antagonistic co-activation is not used as a strategy to increase precision of trunk control. This finding was consistent over different experimental tasks and did not differ between subjects with and without LBP. In addition to the finding that subjects do not increase co-activation to increase precision (chapter 4), the GEE analysis in chapter 3 revealed that any activation of antagonists tended to increase rather than reduce tracking errors. This is in contrast with findings on precision control in the limbs, where joint stiffening by antagonistic co-activation has been shown to reduce kinematic variability and thus increase precision [43-45, 47]. These conflicting findings can be explained by essential differences between the trunk and, for instance, the elbow joint. Due to the trunk’s large mass, and thus high inertia, movement frequency is generally much lower in the trunk than in the elbow. When movements are slower it may be more feasible to use a feedback strategy, since the delays involved with feedback control are relatively smaller (compared to movement time). Important disadvantages of stiffening the trunk by co-activation may be, as outlined in Chapter 1, high metabolic costs, increased compression forces in the spine, and loss of flexibility of the spine. Moreover, co-activation may compromise other functions of trunk musculature, e.g. breathing. These factors may explain why subjects appeared to use feedback control strategies and did not tend to stiffen their trunk by antagonistic co-activation.

Sensory information

The fourth important finding is that indications for proprioceptive impairments in LBP patients were found, which appeared to be task-dependent. In chapter 3, despite the continuous presence of visual feedback of trunk angle (and vestibular feedback), tracking errors increased with lumbar muscle vibration in healthy individuals. Interestingly, vibration did not affect performance in LBP patients. This suggests that LBP patients weight lumbar proprioceptive information lower than healthy controls. Previous studies have already reported lower weighting of proprioception from lumbar muscle spindles relative to calf muscle spindles [52-54], but, to our knowledge, reduced weighting of lumbar proprioception relative to visual information has not been reported before.

The task-dependency of proprioceptive weighting became apparent from the lack of interaction between the factors group and vibration in the static positioning (chapter 4) and
seated balancing tasks (chapter 5) in the same group of LBP patients. In chapter 4, lumbar muscle vibration deteriorated accuracy and precision of an upright trunk posture similarly in subjects with and without LBP. The effects of vibration were largest in the condition with a low precision demand, when no visual feedback was available (since subjects only received visual feedback of trunk angle when they left the target, and time on target was almost always 100%). In that same condition, LBP patients drifted further from the target center when no vibration was applied, which may reflect compromised quality of proprioceptive information on low frequency movements. In chapter 5, vibration only had a marginal effect on seated balancing performance, and this effect did not differ between groups. We therefore concluded that lumbar proprioception may not be an important source of information during this task. In line, a recent study on standing on an unstable surface concluded that the relative importance of proprioception may be reduced when no direct relation exists between proprioceptive feedback and orientation of the body relative to the gravitational field [113]. The effect of vision occlusion during the seated balancing task was also similar between groups.

In conclusion, the weighting of lumbar proprioception probably depends on the availability of other sources of relevant information, and LBP patients may show ‘preferential down-weighting’ of lumbar proprioception when alternative information sources are available. This may be related to a reduced quality of proprioception from the painful area. Future studies could be aimed at further discriminating between the weighting and the quality of lumbar proprioception in LBP patients.

**EMG interpretation**

Moments around the lumbar spine, and thus trunk muscle activation levels are low during control of an upright trunk posture. Therefore the signal-to-noise ratio of EMG signals was low in the studies presented in this thesis. Consequently, interpretation of trunk muscle EMG in these studies was severely hampered by ECG contamination.

Therefore we performed quite rough analyses with EMG amplitudes averaged over muscle groups and/or over time. To avoid introducing a bias between subject groups with and without LBP, we did not use maximal voluntary contractions to normalize these amplitudes. Instead, we calculated ratios of co-activation as an alternative normalization
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and we matched the subject groups in terms of BMI. In addition, we measured skin fold thickness at electrode locations, which did not differ between groups.

When studying trunk control, it is interesting to study temporal patterns of trunk muscle EMG activation in more detail. For instance, correlation measures could discriminate simultaneous co-activation from reciprocal activation of agonist and antagonist muscles. However, when ECG contamination is present in both signals, the R-peaks will largely dominate the correlation coefficient. Since ECG is a systematic source of contamination that can dominate trunk muscle EMG recordings, removal of ECG from EMG can substantially improve the interpretation of EMG. Current methods to remove ECG from EMG recordings have important limitations and therefore chapter 6 described and evaluated a promising alternative method, based on independent component analysis. This may indeed improve interpretation of trunk muscle EMG recordings in future studies, and eventually contribute to a better understanding of impaired muscle recruitment associated with LBP.

**Recommendations for future studies**

One of the main issues with respect to LBP, which was not addressed by the studies described in this thesis, concerns the etiology of LBP. The currently used cross-sectional design does not provide an answer to the famous chicken-or-egg-question, in this case, does LBP cause or result from changes in motor behavior? While changes in motor behavior may reflect adaptations to pain, it is also possible that aberrant motor behavior is causal for LBP. Moreover, adaptations to pain can be beneficial, but could also increase the risk of recurrence and/or chronicity of LBP. This causality of the relation between motor behavior and LBP should be unraveled by longitudinal prospective studies.

While inconsistent results have been found in studies using conventional assessments of proprioception (e.g. active and passive motion detection thresholds and repositioning errors) [131-134], the present results and previous studies with lumbar muscle vibration provide more consistent evidence for local sensory impairments in LBP patients ([52-54], this thesis). However, for now it remains unclear whether proprioceptive deficits are a cause or a consequence of LBP. Therefore we suggest to continue investigating the effect of proprioception disturbance by muscle vibration in longitudinal studies. In addition, the clinical relevance of these findings (e.g. an association between impaired proprioception
and the severity or recurrence of LBP) remains to be elucidated. If a causal relation between impaired proprioception and LBP indeed exists, improving proprioception could be a target of interventions for prevention and treatment of LBP. That would require development of tools and methods to train and to monitor lumbar proprioception.

In seated balancing, LBP patients showed a more extended trunk posture. We could not assess to what extent our unexpected findings of increased lumbar motion and reduced rather than increased preferential recruitment of local relative to global muscles are attributable to the overall trunk posture. A previous study on sitting posture in LBP patients reported that the group averages did not differ between the LBP group and the healthy control group. However, significant differences between healthy individuals and two subgroups of patients were reported; LBP patients either showed ‘more flexed’ or ‘more extended’ trunk postures than healthy controls [107]. Claus and colleagues [78] demonstrated that differences in sitting posture coincide with differences in trunk muscle activation. However, these studies both evaluated sitting on a stable surface. To further investigate the effect of trunk posture on movements and muscle activation during seated balancing, an experiment including explicit instructions on trunk posture could be performed. To improve interpretation of EMG recordings, a separate ECG signal should be recorded.

**Conclusions**

We found indications for impaired quality of trunk control in LBP patients, most convincingly on a tracking task requiring precise circular trunk movements. In contrast with our hypotheses, stiffness regulation of the trunk (by means of antagonistic co-activation) was not used as a strategy to increase precision of trunk control or as a strategy to protect the painful area in LBP patients. LBP patients even demonstrated increased rather than decreased thoraco-lumbar movements, coinciding with a much more upright trunk posture when compared to healthy individuals on a seated balancing task. Furthermore, we found indications for proprioceptive impairments in LBP patients, which may reflect reduced weighting and/or compromised quality of proprioceptive information from lumbar muscle spindles.