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Precision control of trunk movement in low back pain patients

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ABSTRACT

Motor control is challenged in tasks with high precision demands. In such tasks, signal-dependent neuromuscular noise causes errors and proprioceptive feedback is required for optimal performance. Pain may affect proprioception, muscle activation patterns and resulting kinematics. Therefore, we investigated precision control of trunk movement in 18 low back pain (LBP) patients and 13 healthy control subjects. The subjects performed a spiral-tracking task requiring precise trunk movements, in conditions with and without disturbance of proprioception by lumbar muscle vibration. Tracking task performance and trunk muscle electromyography were recorded. In conditions without lumbar muscle vibration, tracking errors were 27.1% larger in LBP patients compared to healthy controls. Vibration caused tracking errors to increase by 10.5% in healthy controls, but not in LBP patients. These results suggest that reduced precision in LBP patients might be explained by proprioceptive deficits. Ratios of antagonistic over agonistic muscle activation were similar between groups. Tracking errors increased trunk inclination, but no significant relation between tracking error and agonistic muscle activation was found. Tracking errors did not decrease when antagonistic muscle activation increased, so, neither healthy subjects nor LBP patients appear to counteract trunk movement errors by increasing co-contraction.

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1. Introduction

Precise motor control is hampered by neuromuscular noise. The exact origin of this noise is still unknown (Christakos, Papadimitriou, & Erimaki, 2006; De Luca, LeFever, McCue, & Xenakis, 1982; Jones, Hamilton, & Wolpert, 2002), but synaptic noise resulting in fluctuations in motor unit firing rates and firing intervals is suggested to be one of the main causes (Matthews, 1996; Selen, Beek, & van Dieën, 2005). Neuromuscular noise is signal-dependent, in that force variability increases with muscle activation level (Allum, Dietz, & Freund, 1978; Christou, Grossman, & Carlton, 2002; Jones et al., 2002; Newell & Carlton, 1988; Sherwood, Schmidt, & Walter, 1988; Slifkin, Vaillancourt, & Newell, 2000; Tseng, Scholz, Schöner, & Hotchkiss, 2003; Visser et al., 2003). The effects of neuromuscular noise become apparent in a lack of precision, for example in aiming and tracking tasks. Performance on such tasks reflects the ability to reduce kinematic variability and can be used as a measure of quality of motor control.

Precise motor control appears to be impaired by pain. Huysmans and colleagues found larger upper limb tracking errors in subjects with shoulder pain compared to pain-free controls (Huysmans, Hoozemans, van der Beek, de Looze, & van Dieën, 2010). It has been suggested that this is due to the effect of nociceptive afference on muscle spindle feedback, which would impair proprioception (Pedersen, Sjolander, Wenngren, & Johansson, 1997). In addition, chronic pain has been shown to cause reorganization in the primary somatosensory cortex (Flor, Braun, Elbert, & Birbaumer, 1997), which may modulate the processing of both noxious and nonnoxious input (Moseley & Flor, 2012). In the study on shoulder pain the reduced precision indeed coincided with a reduced proprioceptive acuity in the pain group (Huysmans et al., 2010). Proprioceptive impairments in low back pain (LBP) patients have been demonstrated using lumbar muscle vibration, which is known to perturb proprioceptive feedback from muscle spindle afferents by inducing a lengthening illusion (Burke, Hagbarth, Lofstedt, & Wallin, 1976; Roll, Vedel, & Ribot, 1989). Brumagne and colleagues found reduced trunk repositioning accuracy in LBP patients compared to healthy controls and, interestingly, paraspinal muscle vibration negatively affected trunk repositioning accuracy in healthy controls, but not in LBP patients (Brumagne, Cordo, Lysens, Verschueren, & Swinnen, 2000). Also, in a variety of postural tasks with vision occluded, the relative effects of lumbar muscle vibration and calf muscle vibration on postural sway differed between LBP patients and healthy controls (Brumagne, Cordo, & Verschueren, 2004; Brumagne, Janssens, Knapen, Claeys, & Suuden-Johanson, 2008; Claeys, Brumagne, Dankaerts, Kiers, & Janssens, 2011). LBP patients tended to use a more ankle-steered strategy, in that their response to calf muscle vibration was larger than their response to lumbar muscle vibration, which might point at a lower weighting of proprioceptive information from lumbar muscle spindles. Moreover, individuals with LBP have been shown to have increased levels of co-activation (van Dieën, Selen, & Cholewicki, 2003), which may indicate a compensatory joint stiffening strategy to deal with impaired proprioception.

Indeed, joint impedance modulation by antagonistic co-activation has been suggested as a means to counteract kinematic variability due to neuromuscular noise. Modeling work suggests that, by activating antagonistic muscle pairs around a joint, joint stiffness increases and kinematic variability decreases in spite of an increase in force variability of each of the muscles separately (Selen et al., 2005). In upper extremity tracking tasks, increased precision indeed coincided with increased joint impedance (Selen, Beek, & van Dieën, 2006; Selen, van Dieën, & Beek, 2006) and EMG activity (Huysmans et al., 2010), suggesting that the tracking error was successfully reduced by antagonistic co-activation.

Thus, whereas increased agonistic muscle activation can reduce precision, antagonistic co-activation can increase precision. In the trunk, however, no evidence for the use of such a co-activation strategy was found in static positioning tasks (Willigenburg, Kingma, & van Dieën, 2010). Instead, feedback control appeared to be used to regulate precision. Given this stronger reliance on feedback instead of co-activation to modulate precision in the trunk compared to the upper extremity and given the proprioceptive impairments associated with pain, we expect LBP to have pronounced effects on precision control of the trunk.

While tracking tasks are often called visuo-motor tasks, proprioceptive feedback is an important source of information in controlling tracking movements (Eidelberg & Davis, 1976; Nagaoka & Tanaka,