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Trunk muscle reflexes are elicited by small continuous perturbations in healthy subjects and patients with low-back pain

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ABSTRACT

Low-back pain (LBP) has been recognized as the leading cause of disability worldwide. Lumbar instability has been considered as an important mechanism of LBP and one potential contributor to lumbar stability is trunk muscle reflex activity. However, due to the differences in experimental paradigms used to quantify trunk mechanics and trunk reflexes it remains unclear as to what extent the reflex pathway contributes to overall lumbar stability. The goal of this work was to determine to what extent reflexes of various trunk muscles were elicited by the small continuous perturbations normally used to quantify trunk mechanics. Electromyographic (EMG) activity was measured bilaterally from 3 trunk extensor muscles and 3 trunk flexor muscles at four epochs: 25–50 ms, 50–75 ms, 75–100 ms and 100–125 ms following each perturbation. Reflex activity was seen in all muscles as 34 of the 48 muscle-epoch combinations showed a significant reflex response to either perturbations in the forward or backward direction. However, the reflex EMG activity did not correlate with mechanical estimates of the reflex response. Thus, even though reflexes are indeed elicited by the small perturbations used to quantify trunk mechanics, their exact contribution to overall lumbar stability remains unknown.

1. Introduction

Low-back pain has been recognized as leading cause of disability worldwide and is only expected to increase in the coming decades as the world's population ages (Hoy et al., 2012). A major contributor to low back pain is insufficient lumbar stability (Panjabi, 2003). Lumbar stability is achieved through numerous mechanisms, including the intrinsic mechanics of the torso (Cholewicki and McGill, 1996; Cholewicki and VanVliet Iv, 2002), feedforward motor control (Silfies et al., 2009) and feedback motor control (Cholewicki et al., 2005; Moorhouse and Granata, 2007). In this paper we will focus on the feedback motor control of lumbar stability, more specifically the role of reflex responses.

Numerous studies have investigated the link between mechanical properties of the torso and low back pain. Biomechanical models have shown that insufficient torso stiffness can lead to injury and low back pain (Cholewicki and McGill, 1996). Experimentally, it has been seen that LBP patients display increased trunk stiffness (Hodges et al., 2009; Miller et al., 2013), which is likely due to different muscle activation strategies displayed by LBP patients (van Dieën et al., 2003).

Another contributor to lumbar stability is the action of reflexes. Indeed, low back pain sufferers display delayed reflex responses, as measured by electromyographic activity (EMG), to both sudden loading (Magnusson et al., 1996; Navalgund et al., 2013) and unloading (Radebold et al., 2000, 2001; Reeves et al., 2005). They also show altered reflex EMG amplitude in loading (Larivière et al., 2010) and unloading (Radebold et al., 2000). While these studies have shown an association between altered reflex EMG and LBP, the extant of functional mechanical changes that result from these altered reflexes remains unclear (Kearney et al., 1999).

While it is widely believed that both altered lumbar stability and altered trunk reflexes are associated with low back pain, the number of studies that have related the mechanical contribution of reflexes to lumbar stability is limited. Hendershot et al. (2011) computed how reflex stiffness changed following prolonged flexion but did not quantify the contribution of reflex stiffness to total trunk stiffness. Moorhouse and Granata (2007) found that the mechanical component of the reflex response, could account for up to 42% of the total static trunk stiffness. Previous results from our lab (Larivière et al., 2015b) were strikingly different, as we

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found that reflex component accounted for less than 3% of the total torque variance. Similarly, van Drunen et al. (2013) found that including a reflex component in their model of lumbar stiffness only increased their model's fit from 87% to 90%, implying that reflexes only contributed a small percentage. The differences in these results raise the question of whether the results presented in these studies are accurate quantifications of the mechanical effects of the reflex component.

One way to ensure that mechanical characterization of reflexes is accurate is to correlate the mechanical reflex results with EMG based ones. However, studies showing this are lacking. One of the main reasons for this disconnect between mechanical and EMG findings is finding a paradigm where mechanics can be estimated and reflexes elicited. Reflexes have been shown to be highly non-linear and vary greatly depending on the type of perturbation (Stein and Kearney, 1995). This is compounded by the fact human body mechanics are also non-linear and can change depending on the type and size of the perturbation (Kirsch et al., 1994; Malamud et al., 1996). Thus perturbations used when estimating mechanics often greatly vary comparatively to those used in experiments that investigate EMG reflex responses. The rapid and continuous perturbing that is common in mechanics studies may cause an inhibition of the reflex response (Crone and Nielsen, 1989). This raises doubt as to whether or not reflexes will be present when the trunk is perturbed with the continuous displacements normally used to characterize trunk mechanics.

Here, in this study, we determine whether torso reflexes are elicited during the small continuous perturbations that are often used in human biomechanics quantification. Doing so would confirm whether reflexes could indeed contribute to typical estimates of torso mechanics and provide insight as to how changes in reflexes affect back mechanics. Furthermore, we examined whether the reflexes elicited by these small continuous perturbations are correlated with the mechanical estimates of reflex stiffness as estimated by three different algorithms. This assesses whether the current models of reflex stiffness truly represent the mechanical effects of the reflex activity.

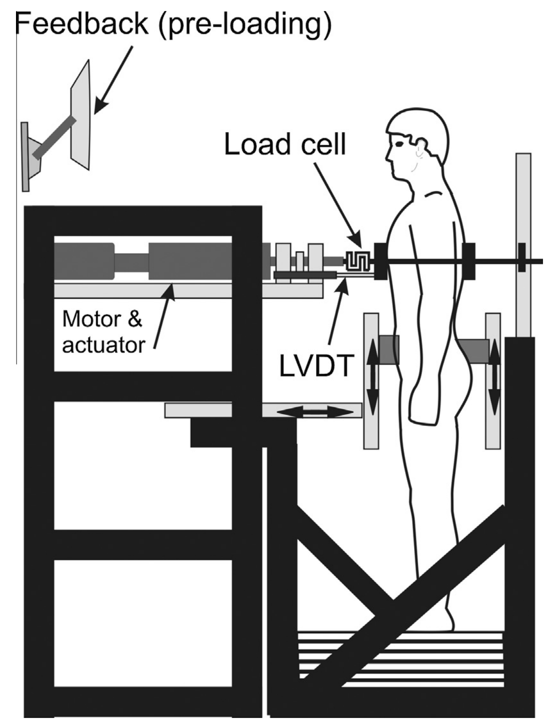

Fig. 1. Schematic of experimental apparatus.

2. Methods

2.1. Subjects

Thirty-six subjects, 18 males and 18 females, ages ranging from 18 to 65 participated in the study. Nineteen of the subjects (9 men and 10 women) had no history of any low back pain, while 17 (9 men and 8 women) of the subjects suffered from low-back pain. Although not of importance for the present study, the selection criteria and description of these subjects are explained in detail in previous work from our lab (Larivière et al., 2015a). All subjects gave informed consent to the experimental procedures, which were approved by the ethics committee of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal.

2.2. Apparatus

A schematic of the experimental setup is shown in Fig. 1. Subjects stood upright with their chest's attached to a linear actuator (T13-B4020MS040, Thomson Radford, VA) powered by an electric motor (AKM54K-ANC2DB800, Kollmorgen, Radford, VA) via an adjustable harness. Subjects were aligned in the apparatus such that the perturbations were applied at the T8 level. Subjects' chest positions were measured using a linear variable differential transformer, LVDT, (LD610-50, Omega, Stamford, CT) and linear torso forces were measured using a load cell (SM-5000N, Interface, Scottsdale, AZ). Data from the LVDT and load cell were sampled at 1 kHz (NI PCI-6229, National Instruments, Austin, TX). Electromyographic (EMG) activity was measured bilaterally from 3 torso extensor muscles—longissimus (LO), iliocostalis (IL) and multifidus (MF)—and 3 torso flexor muscles—rectus abdominus (RF), internal oblique (IO) and external oblique (EO)—using bipolar surface electrodes (De-2.3, Delsys Inc. Wellesley, MA; bandwidth 20 ± 5 Hz to 450 ± 50 Hz, 12 dB/oct; preamplification gain: 1000; CMRR: >80 dB; noise) composed of two parallel silver bars (10 mm long, 1 mm wide) spaced 10 mm apart. Prior to application of the electrodes, the skin was shaven and abraded with alcohol. The exact location of the electrodes is compliant with SENIAM standards, and consistent with our previous studies (Larivière et al., 2001, 2014b). Prior to recording the EMG signals, the data were band-pass filtered between 20 and 450 Hz as has been done in previous studies on trunk muscles (Oomen et al., 2015) (see (De Luca et al., 2010; Van Boxtel, 2001) for justification on the use of the 20-Hz high pass filter).

2.3. Protocols

32 of the 36 subjects participated in two experimental sessions on separate days; the other 4 only participated in one experimental session.

Each experimental session commenced with submaximal voluntary contractions (sMVC). Substantiating the trunk muscle activation level requires an adequate method to normalize EMG amplitude values, which ideally requires a maximal EMG reference value obtained during a maximal voluntary contraction (MVC). Unfortunately, MVCs may be biased by pain-related fears in subjects with LBP, which generates lower "maximal" EMG reference values (Thomas et al., 2008). Consequently, sMVCs were carried out according to published procedures that have been found to produce reliable results for abdominal (Dankaerts et al., 2004; O'Sullivan et al., 1998) as well as back muscles (Dankaerts et al., 2004). Three 5-s contractions, separated by a 30-s rest interval, were performed for each muscle group. Briefly, the abdominals were recruited while performing a double leg raise exertion