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Assessing delay and lag in sagittal trunk control using a tracking task

N. Peter Reeves [a,*], Abraham Luis [b,c], Elizabeth C. Chan [d], Victor G. Sal y Rosas [e], Martin L. Tanaka [f]

[a] Sumaq Life LLC, USA
[b] Laboratorio de Investigacion en Biomecanica y Robotica Aplicada, Peru
[c] Seccion de Ingenieria Mecanica, Pontificia Universidad Católica del Perú, Peru
[d] Department of Physical Medicine and Rehabilitation, New York University School of Medicine, USA
[e] Sección de Matemáticas, Departamento de Ciencias, Pontificia Universidad Católica del Perú, Peru
[f] School of Engineering and Technology, Western Carolina University, USA

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ABSTRACT

Slower trunk muscle responses are linked to back pain and injury. Unfortunately, clinical assessments of spine function do not objectively evaluate this important attribute, which reflects speed of trunk control. Speed of trunk control can be parsed into two components: (1) delay, the time it takes to initiate a movement, and (2) lag, the time it takes to execute a movement once initiated. The goal of this study is to demonstrate a new approach to assess delay and lag in trunk control using a simple tracking task. Ten healthy subjects performed four blocks of six trials of trunk tracking in the sagittal plane. Delay and lag were estimated by modeling trunk control for predictable and unpredictable (control mode) trunk movements in flexion and extension (control direction) at movement amplitudes of 2°, 4°, and 6° (control amplitude). The main effect of control mode, direction, and amplitude of movement were compared between trial blocks to assess secondary influencers (e.g., fatigue). Only control mode was consistent across trial blocks with predictable movements being faster than unpredictable for both delay and lag. Control direction and amplitude effects on delay and lag were consistent across the first two trial blocks and less consistent in later blocks. Given the heterogeneity in the presentation of back pain, clinical assessment of trunk control should include different control modes, directions, and amplitudes. To reduce testing time and the influence of fatigue, we recommend six trials to assess trunk control.

1. Introduction

Slower trunk control appears to be a risk factor for back pain, which is clinically overlooked. It has been shown that the spine is inherently unstable (Crisco et al., 1992) and that some level of trunk muscle coactivation is required to prevent the spine from buckling (Cholewicki et al., 1997). More recently, the spine has been viewed as a dynamic system in which not only the level of trunk muscle activation is important but also the timing of activation (Granata et al., 2004; Liebetrau et al., 2013; Reeves et al., 2007, 2011; van der Burg and van Dieen, 2001; van Drunen et al., 2013). The importance of timing of activation is reinforced by findings that people with back pain have longer latencies in trunk muscle reflex responses (Magnusson et al., 1996; Radebold et al., 2000, 2001; Reeves et al., 2005; Wilder et al., 1996), those with longer latencies are more predisposed to future back injuries (Cholewicki et al., 2005), and longer latencies in trunk muscle reflexes negatively affect postural control (Franklin and Granata, 2007; Oomen et al., 2015; Reeves et al., 2009). There is evidence to suggest that some aspect of delays found in people with back pain can be attributed to additional delays in central processing of information (Luoto et al., 1998, 1996, 1999). In addition, important spine stabilizing muscles are reduced in size following back injury (Hides et al., 1994; Hodges et al., 2006), which may impact their ability to quickly respond to spine disturbance. Therefore, both delay in sending a motor command and lag in executing a motor command may leave the spine prone to injury. Unfortunately, objective clinical tests do not exist to assess how quickly the trunk can be controlled, and as a consequence, clinically meaningful impairments in trunk control are overlooked.

Trunk control delay and lag represent different neurophysiological events and assessing these control attributes may help identify sources of impairment. Delay represents the time that it takes to transmit signals through the system. For instance, it takes time for an action potential to propagate along the nerve to transmit information. In the case of the action potential, the shape of the

* Corresponding author at: Sumaq Life LLC, 712 Audubon Road, East Lansing, MI 48823, USA.
E-mail address: reevesn@icloud.com (N.P. Reeves).

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signal is not changed, but instead is delayed by some time period. In contrast, system dynamics result in lag that changes the shape of the signal. For instance, the conversion of an electrical input (i.e., action potential) to mechanical output (i.e., muscle force) has dynamics, which makes the shape of the mechanical output different than the electrical input. As the signal undergoes an electromechanical transformation, the initial signal changes by losing higher frequency content. Lag can be thought as a low pass filtering effect. This low pass filter also affects control speed since the rate at which control input can be applied is reduced. Therefore, to assess speed of trunk control both delay and lag should be quantified. This information could provide insight into possible sources of neuromuscular impairment in back pain patients that could guide treatment.

The goal of this project is to demonstrate a new approach to assess delay and lag in trunk control using a simple tracking task. We have shown in our previous research that position tracking, moving the trunk to track a target on a screen, can reliably assess trunk control (Reeves et al., 2014). In this paper, we will compare delay and lag under a variety of trunk control conditions, including different modes (predictable vs unpredictable tracking), directions (flexion vs extension) and amplitudes of movement (2° vs 4° vs 6°), and evaluate consistency in these measures over blocks of trials. Consistency in trunk control can be affected by learning (not enough trials) or fatigue and/or reduced motivation (too many trials). To determine how many trials should be performed, we assessed the main effects of control mode, direction, and amplitude of movement across blocks of trials to identify when secondary influencers (e.g., fatigue) affected delay and lag measures.

2. Methods

2.1. Subjects

Ten healthy subjects were recruited for the study. Seven were male and 3 were female; the median age was 25 years (IQR: 21–37, range: 20–58); the median height was 173.2 cm (IQR: 169.5–175.8, range: 160–184.4), and the median weight was 77.5 kg (IRQ: 71.1–81.08, range: 54.8–105.6). Subjects were excluded if they had a neurological condition (e.g., Parkinson's disease, multiple sclerosis, cerebral palsy, Alzheimer's disease, amoytrophic lateral sclerosis), balance or coordination problems, were blind or possibly pregnant, or were unable or unwilling to give written consent. Michigan State University Biomedical and Health IRB approved the research protocol. All subjects signed an informed consent form prior to testing.

2.2. Data collection

Fig. 1 depicts the components for a generic trunk control system. These components include the plant, denoted by P, (i.e., subject anthropometrics) and the controller, denoted by K, (i.e., control logic regulating trunk behavior). The overall objective for the trunk control system is to have the output signal, which represents the movement of the trunk, y(t), track a reference signal, which represents a position target, r(t), in order to minimize the error between the two signals, $e(t) = r(t) - y(t)$.

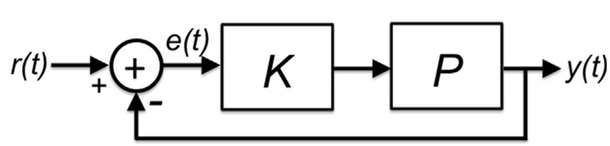

Fig. 1. Block diagram depicting the input-output model for the trunk tracking task. r(t) represents the target to be tracked, y(t) represents the position of the trunk, and e(t) represents the error in tracking.

Trunk control was assessed using position tracking in the sagittal plane. The experimental set-up included a seat with a pelvic restraint, string potentiometers (Celesco SP2-50, Chatsworth, CA) to record angular trunk position, and a monitor (Samsung SyncMaster SA650; height 27 cm, width 47.7 cm) located 1 m away from the subject at eye level to display both reference input r(t) and the output y(t) signals (Fig. 2). Gross trunk angle was estimated from the two string potentiometers connected to a chest harness with the upper string potentiometer located approximately at T5 spinal level and the lower string potentiometer at T10 spinal level. A trigonometric conversion was used to calculate trunk angle using the differences in length between the two string potentiometers. Prior to performing the tracking task, subjects were instructed to sit upright in a neutral lumbar spine position to establish the 0° trunk position.

For the tracking task, subjects were instructed to track the moving target "as fast and accurately as possible" in order to keep their trunk position y(t) on the reference signal r(t). The reference signal r(t) during the tracking task represented a series of step responses (see Fig. 3). The position of the reference signal switched among one of seven points along a vertical axis on the screen corresponding to trunk flexion of 2°, 4°, or 6°, neutral at 0°, and trunk extension of −2°, −4°, or −6°. Each non-zero trunk position occurred twice for each trial in random order. The signal always started at 0°, then moved to one of the flexion/extension positions, and then back to 0° creating a square wave trajectory. At 0°, the signal was held for 4, 5, or 6 s to produce a random aspect to the hold time in this position. At the flexion/extension positions, the signal was always held for 5 s, making returning to the neutral position more predictable, although the subjects were not explicitly informed that the hold time was 5 s. This type of signal allowed for the assessment of both unpredictable (i.e., moving away from neutral) and predictable tracking (i.e., returning to neutral), thus giving insight into both feedback and feedforward control. Subjects performed 4 blocks of 6 trials with approximately 1 min of rest between each block.

2.3. Data analysis

An algorithm was implemented to classify step responses into unpredictable/predictable tracking (moving away from 0°/return-

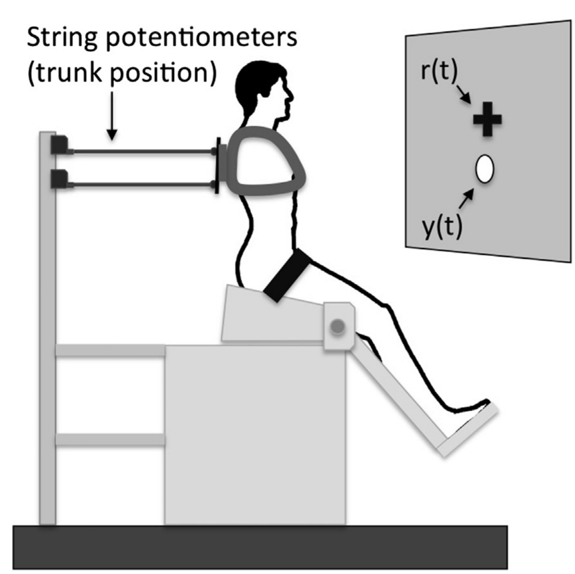

Fig. 2. Experimental set-up for trunk tracking. r(t) represents the target while y(t) represents the position of the trunk in the sagittal plane.