Human Movement Science 44 (2015) 277–286

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Fitts's Law using lower extremity movement: Performance driven outcomes for degenerative lumbar spinal stenosis

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ARTICLE INFO

Article history:
Received 11 February 2015
Revised 23 September 2015
Accepted 23 September 2015
Available online 2 October 2015

Keywords:
Fitts's Law
Spinal stenosis
Kinematic analysis
Motor processes

ABSTRACT

A paucity of objective outcome measures exists for assessing movement disorders, including degenerative lumbar spinal stenosis (LSS). Fitts's Law provides a novel approach to clinical outcome measurement since performance is resistant to learning, and task difficulty can be altered. The objective of the present study was to compare, using a Fitts's task, movement performance of individuals with and without LSS to determine if motor difficulties that arise with LSS impede the planning, initiation, or execution of deliberate lower limb movements. Twelve pre-surgical LSS patients and twelve control participants from the community performed a Fitts's Law (foot reaching) task, while LSS participants also completed pain and disability questionnaires. Fitts's Law was evident for both groups, however the LSS group's movements were more adversely impacted as task difficulty increased. Specifically, the LSS group's movement time and time to peak velocity (ttPV) increased as task index of difficulty increased, while peak velocity decreased. Correlations between ttPV and leg pain, and with stenosis impairment severity respectively, provided evidence that less support leg pain and less stenosis impairment severity yield faster ttPV in the moving leg at the highest index of difficulty. Therefore a lower extremity Fitts's Law task captured differences in the planning and execution of leg movements between healthy and LSS populations.

1. Introduction

A common cause of low back pain is lumbar spinal stenosis (LSS). Observable features of LSS are a narrowing of the central canal and/or intervertebral foramen through which the spinal cord and/or nerve roots traverse. The causes of LSS may include, but are not limited to, trauma, degeneration, or birth-defect (Katz & Harris, 2008). Incidence rates of 8–11% have been reported for LSS (Jenis & An, 2000) and it is also the most common reason for individuals aged 65 years or older to proceed to spinal surgery (Ciol, Deyo, Howell, & Kreif, 1996).

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http://dx.doi.org/10.1016/j.humov.2015.09.010
0167-9457/

Outcome measures provide a metric to help clinicians identify and report clinical change in patients (Passmore & Descarreaux, 2012). Appropriate outcome measures can be used to assess improvement or regression at different points of time in the healthcare continuum. For example, baseline and follow-up measures surrounding a course of inexpensive conservative care may provide evidence that an expensive surgical care procedure is not clinically warranted. That said, without sensitive or specific outcome measures clinicians and patients are less able to monitor change. Presently there is a lack of sensitive and specific outcome measures to monitor the progression and treatment of LSS (Pratt, Fairbank, & Virr, 2002). This paucity is particularly apparent when evaluating the functional motor abilities of individuals with LSS, which is of interest because a primary complaint of LSS patients is a noticeable decrease in motor ability, including ambulation (Katz & Harris, 2008). Motor performance-based outcome measures are a promising option for monitoring the progression and management of LSS because they reflect a patient's ability to carryout movement based activities commonly executed during daily living.

To rectify the lack of performance-based outcome measures we turn to the large evidence base built by motor control researchers for the measurement of human motor performance. When determining the difficulty of the motor task to apply, the optimal level of challenge for both healthy and impaired individuals should be considered based on both performer skill level, and the inherent difficulty of the task. Specific predictions regarding the optimal challenge point are captured in a framework known as the challenge point framework (Guadagnoli & Lee, 2004). If the task is too difficult for a performer it will result in a floor effect. Conversely, if it is too simple a ceiling effect of performance will result. Therefore, a motor task with varying levels of difficulty is optimal to determine what is too difficult or too simple for a population. Since the performance-based measure should be applied at baseline and at later follow-up point(s), a motor task resistant to learning effects is also needed. Given the above criteria we selected a classic model from the motor control literature, Fitts's Law (Fitts, 1954; Fitts & Peterson, 1964). Fitts's Law is both resistant to learning and has varying levels of task difficulty (Schmidt & Lee, 1999). It uses a mathematical equation to calculate task difficulty of rapid aiming movements as a function of distance and target width. This robust model has received tremendous support in the more than 60 years since its inception and is one of only two laws of Motor Behavior, (Beamish, Bhatti, MacKenzie, & Wu, 2006). According to Fitts's Law movement time (MT) increases linearly based on the equation MT = a(ID) + b; where a and b are constants and the ID, or index of difficulty, is defined by the target size (W) and the amplitude of the movement (A). Specifically: $\text{ID} = \log_2(2A/W)$ (Fitts, 1954; Fitts & Peterson, 1964). Of relevance to the present study, Fitts and Peterson (1964) replicated Fitts's Law in a discrete aiming task context. Previous comparative investigations utilizing Fitts's Law discrete aiming tasks have found measureable differences between young healthy populations, and those who are older (Passmore, Burke, & Lyons, 2007), or in pain (Descarreaux, Passmore, & Cantin, 2010).

The purpose of the present experiment was to apply Fitts's Law to assess movement performance at various IDs to determine if the motor difficulties that arise with LSS can be identified through changes in the planning, initiation, or execution of deliberate lower limb movements. The present study also assessed the relationship for LSS patients between movement performance ability and scores on traditional questionnaire-based outcome measures in order to identify any relationships between self-reported pain/performance and measured movement performance.

2. Method

2.1. Participants

Twelve participants with degenerative LSS (2 females, age 55–67 years, $M = 61.6$, $SD = 4.0$) and twelve healthy adults (8 females, age 47–79 years, $M = 57.4$, $SD = 8.0$) participated in the study. Footedness was determined using the Waterloo Footedness Questionnaire (Elias, Bryden, & Bulman-Fleming, 1998). The Waterloo Footedness Questionnaire (WFQ-R) is an instrument used in the consideration of foot preference. Half of the questions assess foot preference for manipulating objects (ex. kicking a ball), while the other half of the questions consider the preferred foot for providing support (ex. balancing on one foot). Question responses (5 per question) are assigned a value between −2 and 2. Scores closer to zero reflect equal preference, negative scores reflect left preference, and positive scores reflect a right preference (Elias et al., 1998). Those recruited were predominantly right-footed in both the control ($M = 8.5$, $SD = 6.9$) and LSS ($M = 8.3$, $SD = 9.3$) groups respectively. Participants with LSS were diagnosed and assessed clinically by an orthopedic spine surgeon at the local Health Sciences Centre. All LSS participants were pre-surgical, had diagnostic imaging and clinical testing/history confirming the diagnosis of LSS. Eligible participants were given information about the study and were able to meet with the study investigators for more information, as outlined by the local research ethics board. An a priori power calculation ($\beta = 0.8$, $\alpha = 0.05$) with published Fitts's Law movement time data for an age appropriate population determined a sample size of 12 participants per group was sufficient.

2.1.1. LSS inclusion criteria

(1) Age over 45, (2) unilateral or bilateral lower extremity pain (defined as pain below the level of the buttock on the anterior or posterior side) with or without back pain, (3) pain worse with walking, (4) pain worse with lumbar extension, (5) pain better with sitting, (6) lumbar spine magnetic resonance imaging (MRI) or computerized tomography (CT) report that