# WFC - NCMIC Lou Sportelli Research Award 2017

# Impact of Spinal Manipulation on Lower Extremity Motor Control in Lumbar Spinal Stenosis Patients: A Small-Scale Assessor-Blind Randomized Clinical Trial

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## Abstract

**Objective:** The purpose of this study was to quantify the impact of a single lumbar spinal manipulation (SM) intervention on the leg movement performance of degenerative lumbar spinal stenosis (LSS) patients in a small-scale registered randomized clinical trial.

**Methods:** Participants with LSS (n = 14) were tested at baseline for pain, lumbar range of motion, and behavioral or kinematic motor performance (using an established Fitts' Law foot-pointing task), then underwent covariate adaptive randomization to receive SM or no intervention. Postintervention all dependent measures were repeated. Experimenters were blinded to patient group allocation. University ethics board approval was attained.

**Results:** For the primary outcome movement time, there was no significant difference between groups. As predicted by Fitts' Law, all participants had longer movement times as task difficulty increased. Secondary kinematic outcomes yielded no significant between-group differences. Consistent with Fitts' Law, kinematic measures changed significantly with task difficulty. Pairwise comparisons revealed the kinematic variables were more adversely affected by greater movement amplitudes than target size changes. No exploratory differences in pain or lumbar range of motion were observed.

**Conclusion:** Changes in motor performance were not observed in this chronic pain population after a single SM intervention compared with a control group. Given the sample size, the study may have been underpowered to detect meaningful differences. Fitts' Law was observed for the lower extremity–pointing task for an LSS population and may provide an objective measure of motor performance. (J Manipulative Physiol Ther 2019;42:23-33)

**Key Indexing Terms:** *Manipulation, Spinal; Spinal Stenosis; Outcome Assessment (Health Care); Chiropractic*

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## Introduction

Lumbar spinal stenosis (LSS) is a common cause for spine surgical referrals for low back pain.[1] It is caused by a narrowing of the central canal or intervertebral foramen through which the spinal cord or nerve roots pass.[2] There are several potential causes that may lead to LSS, including trauma, degeneration, or birth defect.[2] With a prevalence of 8% to 11%,[3] LSS is the predominant reason for spinal surgery in individuals aged 65 years or older.[4] Even with the high number of patients who experience LSS, there is a lack of sensitive and specific outcome measures that accurately assess the progression and management of LSS.[5] The lack of outcome measures is particularly apparent when assessing the functional motor abilities of this population, which is challenging because an early complaint among LSS patients presurgery is the noticeable decrease in lower-extremity motor capability, including ambulation.[2]

Work previously conducted in our laboratory has shown the usefulness of using a performance-based outcome measure, which is built upon a large and strong body of theoretical evidence from the field of human motor control.[6,7] The outcome measure is based on a practical application of Fitts' Law applied to lower-extremity movement.[6,7] Fitts' Law[8,9] has received consistent support because its robustness, resistance to learning, varying levels of difficulty, and applicability to various conditions.[10,11] Fitts' law states that in goal-directed movements, movement time (MT) changes according to the movement amplitude (A) and target width (W). This law is mathematically represented by $MT = a + b\log_2(2A/W)$, where MT is movement time, $a$ and $b$ are empirical constants, and A and W are movement amplitude and target width, respectively. The logarithmic function of the previous formula is called index of difficulty (ID), where $ID = \log_2(2A/W)$, and is measured in binary digits, referred to as bits.[12] According to Schmidt and Lee (2011), a *bit* is "the amount of information required to reduce the original amount of uncertainty by half."[12] The concept of bits originated from information theory. In other words, Fitts' Law can be described as the relationship between MT and task difficulty. During goal-directed movements, MT increases with task difficulty.[8,9] By using a Fitts' Law task, patients with LSS demonstrate longer MT, smaller peak velocities, and longer times to reach that peak velocity when executing goal-directed lower-extremity movements compared to non-LSS individuals. Moreover, the extent of the differences in the previous measures was exacerbated as the difficulty of the task increased.[6,7]

There is evidence that spinal manipulation (SM) for individuals with LSS can aid in pain relief and improve function.[13,14] However, previous studies have largely relied on questionnaire-based outcome measures, which may be subject to bias owing to psychological comorbidity.[15] Therefore, an objective measure of SM as a clinical intervention is worthy of exploration. Performance-based outcome measures including range of motion (ROM) and established motor control tasks can be used to objectively measure the efficacy of SM as a clinical intervention.[16] Fitts' Law tasks have the benefits of being resistant to learning effects and having modifiable levels of difficulty, which can be used to detect differences as performance-based outcome measures. When using a performance-based outcome measure of a clinical intervention, it is important that the task is resistant to learning effects as any improvement may be attributed to motor learning and not the intervention itself. Further, performance of Fitts' tasks may demonstrate functional changes after even a single SM intervention.[17,18]

There are 2 main knowledge gaps of previous research on performance-based outcome measures related to SM and LSS. The first is that performance-based outcome measures have not been applied to symptomatic patient populations with specific diagnoses. The second is that kinematic variables, although they have been used among patients with neck pain,[19] have not been used to assess patients after lumbar SM as a clinical intervention. The benefit of using kinematic variables is that they not only provide insight to the general movement kinematics, but also can be interpreted to reveal details related to planning, execution, and online control of movement.[6,7] It is advantageous to know such details related to motor control of movements, especially among patients who underwent a clinical intervention, because it provides understanding of the impact of commonly used treatments. Small-scale trials that explore the feasibility of employing an understudied intervention on specific clinical populations are justified because they aid in determining whether comprehensive or multilevel evaluations are eventually warranted.[20]

The purpose of this study was to quantify the effect of a single SM intervention, among patients with degenerative LSS, on their motor performance using a recently established lower-extremity movement task.[6,7] We hypothesized that patients who received SM would demonstrate improved coordinated motor performance compared to a control group, most likely through changes in MT.

## Methods

### Participants

Fourteen patients with degenerative LSS ($n$ = 14; Swiss Spinal Stenosis score of $M$ = 63.2, standard deviation [SD] = 15.9) were recruited from a surgical waitlist, baseline tested, and randomized using a covariate-adaptive randomization method for group allocation. The clinician was unaware of baseline testing performance. The initial patient was randomized to either receive SM or no intervention (NI) using a binary coin toss by the clinician. Subsequent patients were randomized to the group opposite the preceding patient in an alternating fashion to maintain balanced groups. Each individual participant's group allocation was concealed on a

paper form in an opaque envelope by the treating clinician from the experimenters. The experimenters recording all dependent measures were blinded to group allocation, and participants were instructed by the clinician not to discuss whether they believed they received a clinical intervention or not with the experimental team. A no-intervention control group as opposed to an attempted sham or placebo was used because of the inherent difficulty associated with successfully identifying a noninert placebo and blinding a manual therapy intervention.[21] Groups included either the intervention (SM) group (n = 7; M = 59.1 years, SD = 9.3; 4 female) or NI control group (n = 7; *M* = 58.9 years, SD = 12.6; 3 female) in a parallel group 1:1 allocation ratio design. Because the study was conducted in a single day, no participants randomly assigned from either group were lost to follow-up. All participants received their intended treatment, and all 14 participants were included in all analyses. Being a small-scale feasibility study, no formal sample size was calculated, and the data generated by this study may be used to inform sample size calculation in future larger-scale clinical trials.[22] An orthopedic spine surgeon performed diagnostic imaging and clinical testing of all participants to confirm LSS diagnosis. Diagnostic imaging results were used to exclude participants with trauma, tumor, or infectious processes that are contraindications of SM. All participants were on a waitlist for spine surgery. After baseline testing, a licensed spine care clinician (chiropractor) gathered medical history and performed a physical examination of all participants to rule out any contraindications to lumber SM before intervention. All participants were deemed to have no contraindications to SM intervention.

***Inclusion Criteria.*** To be included in the study patients met the following criteria: (1) age over 45; (2) unilateral or bilateral lower-extremity pain (pain below the buttock level on the anterior or posterior side) with or without back pain; (3) increased pain during ambulation; (4) increased pain with lumbar extension; (5) decreased pain with sitting; and (6) magnetic resonance imaging or computerized tomography report from the lumbar spine region that included a description of lateral recess, lateral canal, foraminal, or central stenosis.

***Exclusion Criteria.*** Participants were excluded for any of the following reasons: (1) radiculopathy by causes including herniated disc (without evidence of bony or ligamentous stenosis), synovial cyst, epidural lipomatosis, or spinal infection including epidural abscess, postsurgical adhesions, benign or malignant tumor; (2) claudication symptoms believed to be of vascular etiology; (3) lumbar spine vertebral fracture; (4) destructive joint pathology including lumbar spine rheumatoid arthritis; (5) bowel or bladder dysfunction (with associated leg pain); (6) history of lumbar spine surgery (past 6 months); (7) average scores of <30 on quadruple numeric rating scales; (8) unable to verbally communicate or write in English; (9) medicolegal involvement; (10) cardiac pacemaker; (11) seizures or epilepsy history; (12) implanted surgical hardware; and (13) previous documented mental illness.

All participants provided written informed consent to the research coordinator, and the health research ethics board at the University of Manitoba approved this study. All data were collected in a rehabilitation hospital with a motor behavior research laboratory on the same floor as the treatment room. All recruitment, intervention, and follow-up occurred between July and December 2015. The trial was ended when a balanced pool of participants was collected for each group. Participants completed a battery of questionnaire-based outcome measures, which included 3 quadruple numeric rating scales (1 for low back pain, 1 for each left and right leg pain), the Swiss Spinal Stenosis,[23] and the Waterloo Footedness Questionnaire–Revised.[24] Also, the width and length of the distal pad of the great toe was measured bilaterally. The study is a registered clinical trial: NCT02118103 with ClinicalTrials.gov.

## Apparatus

A 23-inch projected image was positioned in front of the participant on a surface parallel to the floor and facing the ceiling on a custom-built support frame and platform. A reed switch was mounted on the support frame platform on the edge proximal to the participant and was defined as the home position. Custom software was used to generate the projected images, track switch-initiated timing, and trigger or synchronize 3-dimensional movement recordings. An infrared emitting diode was placed on the distal aspect of the great toe using a customized removable brace.

## Procedure

Participants stood on the platform with bare feet and a magnet on the medial side of their great toe pad. The magnet closed the reed switch, indicating the home position. A visual precue, which was a black cross in the center of the projected image, alerted the participant that the next trial was about to begin at a variable time (2000-2550 milliseconds) after the precue. Participants were required to use discrete foot aiming movements to reach forward in the sagittal plane with their great toe pad to touch the center of the targets that were generated within the projected image as quickly and as accurately as possible. Targets projected appeared with widths of either 2.5 cm or 5 cm and required movement amplitudes of either 20 cm or 40 cm. The movement amplitudes and target widths served as Fitts' Law A and W, respectively. The 4 possible combinations of As and Ws yielded 4 IDs: 3, 4a, 4b, and 5 bits (IDs 4a and 4b overlap but have different A and W combinations). The 4 combinations were presented in random order, with each combination presented 10× for a total of 40 trials. The procedure was performed for both feet, yielding a total of 80 trials. Each round of trials required less than 10 minutes to perform, and the order of foot use was randomly assigned (Fig 1).

Active lumbar ROM was quantified for all participants using electrogoniometry (Dualer IQ Pro, JTECH Medical,

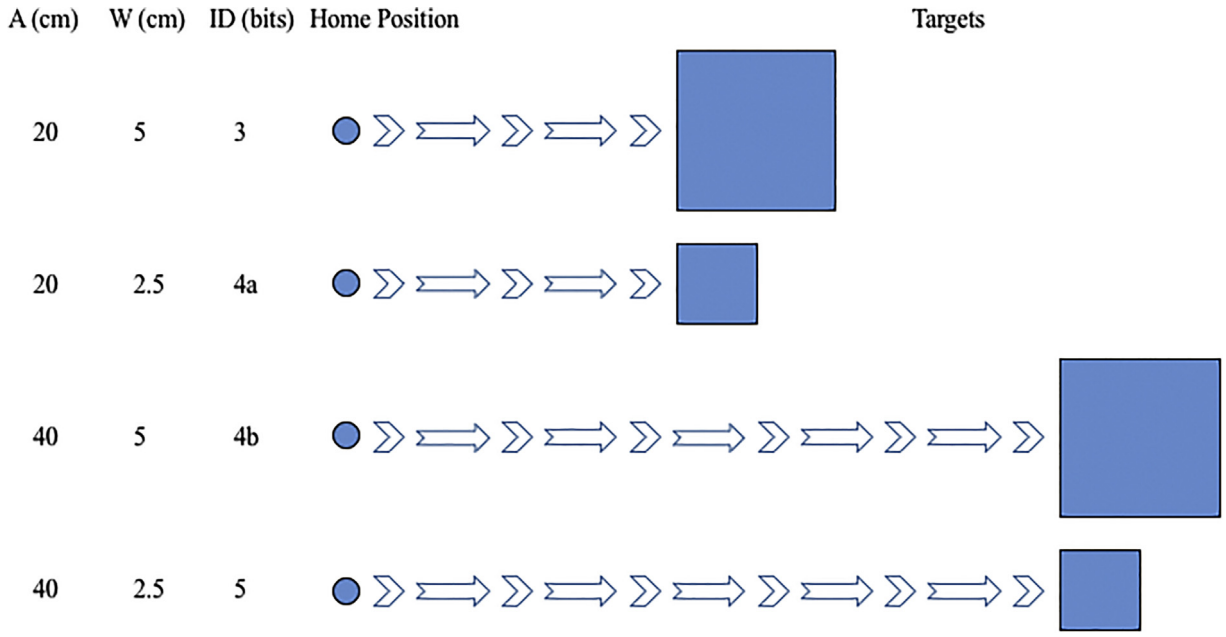


**Fig 1.** *Fitts' task conditions.* A, *amplitude;* ID, *index of difficulty;* W, *target width.*

Midvale, Utah), and then participants were randomized to either SM or NI groups. Participants in the SM group received bilateral high-velocity, low-amplitude SM directed toward the lumber region by a licensed chiropractor with more than 10 years of clinical experience or waited 5 minutes if they were assigned to NI group. The high-velocity, low-amplitude lumbar SM procedure was a hypothenar spinous pull while patients lay in side posture on a chiropractic table.[25] Participants in the NI group were kept blinded to whether they would receive SM later during the study. After the intervention (SM) or after a 5-minute wait (NI), all participants repeated the 80 performance trials, had a reassessment of lumbar ROM, and repeated the numeric rating scale questionnaires. Participants then were escorted out by the treating clinician and had the opportunity to report any harms or unintended effects of treatment. No adverse events were reported. Experimenters were blinded regarding patient group allocation.

### Dependent Variables

***Questionnaire and Performance Measures.*** Questionnaire-based outcome measures were used to quantify baseline characteristics of all participants. Active lumbar ROM (in degrees) for forward flexion, extension, bilateral flexion, and bilateral rotation for all participants was collected. Range of motion was compared between groups after intervention (or NI).

***Behavioral Measures.*** For the pointing task, the primary dependent measure was MT, measured in milliseconds and considered relative to task difficulty. Secondary dependent variables including reaction time (RT) in milliseconds and spatial endpoint accuracy in millimeters were also recorded and considered relative to task difficulty. The time between the presentation of the target to the lift off from the home position of the toe reaching toward the target was defined as RT. The time between toe lift off from the home position and contact with the target was the MT. Spatial endpoint accuracy was the distance from the center of the toe pad touchdown location to the center of the target.

***Kinematic Measures.*** Additional secondary dependent variables included displacement (in mm), peak velocity (m/s), and time to peak velocity (milliseconds), which were recorded and considered relative to task difficulty. Displacement was the distance from the start position to the target. Peak velocity was the point of greatest velocity of the great toe in the plane of movement toward the target. Time to peak velocity was the point in milliseconds at which the great toe reached peak velocity in the plane of movement toward the target.

### Statistical Analysis

For all behavioral and kinematic measures, separate 2 Group (SM, NI) × 2 Time (Pre, Post) × 4 ID mixed-model analysis of variance, with group as the between-subject factor and time and ID as repeated measures, were performed using a random intercept. Significant interactions between group and time were necessary to identify differences between treatment groups over time. For significant effects with more than 2 means, post hoc tests were done using Bonferroni pairwise comparisons. Alpha was set to 0.05 for all omnibus tests, and all statistical analyses (including post hoc tests)

**Table 1.** *Participant Demographics and Questionnaire Descriptive Statistics*

| Demographics and Questionnaires | Overall (N = 14) | SM (N = 7) | NI (N = 7) |
|---|---|---|---|
| Sex | | | |
| Female, n (%) | 7 (50) | 4 (57.1) | 3 (42.9) |
| Male, n (%) | 7 (50) | 3 (42.9) | 4 (57.1) |
| Age, mean (SD) | 59.0 (10.6) | 59.1 (9.3) | 58.9 (12.6) |
| SSS, mean (SD) | 63.2 (15.9) | 67.6 (11.0) | 58.8 (19.5) |
| QNRS, mean (SD) | | | |
| Back | 53.3 (20.1) | 65.7 (14.7) | 41.0 (19.1) |
| Left leg | 34.0 (27.7) | 33.3 (28.2) | 34.8 (29.4) |
| Right leg | 33.6 (22.3) | 40.5 (22.7) | 26.7 (21.2) |
| NRS, mean (SD) | | | |
| Back | | | |
| Pre | 3.5 (3.1) | 4.9 (3.1) | 2.1 (2.5) |
| Post | 4.2 (3.5) | 5.0 (3.9) | 3.4 (3.2) |
| Left leg | | | |
| Pre | 2.1 (3.0) | 1.6 (3.4) | 2.6 (2.8) |
| Post | 2.9 (3.5) | 1.9 (3.0) | 4 (3.9) |
| Right leg | | | |
| Pre | 1.6 (2.1) | 2.4 (2.5) | 0.8 (1.2) |
| Post | 2.8 (2.5) | 3.4 (2.8) | 2.1 (2.3) |

*NI*, no intervention; *NRS*, numeric rating scale; *QNRS*, quadruple numeric rating scale; *SD*, standard deviation; *SM*, spinal manipulation; *SSS*, Swiss Spinal Stenosis score.

were conducted using IBM SPSS Statistics version 24.0 (IBM Corp, Armonk, New York).

For each dependent variable, the mean performance of 20 trials (ten trials per foot) at each ID was used for statistical analysis. All statistical analyses were conducted based on the original group assignments, and each group contained 7 participants. To test whether the assumptions for parametric tests were met, normality was checked using the Shapiro-Wilk test, and homogeneity of variance was tested using Levene's test. The data analyzed both were normally distributed and demonstrated homogeneity of variance.

## Results

### Questionnaire and Performance Measures

No differences were found within or between groups in pain postintervention or lumbar ROM postintervention upon exploratory analysis. Descriptive statistics summarizing baseline group characteristics, questionnaires, and active lumbar spine ROM are summarized in Tables 1 and 2.

### Behavioral Measures

Analysis of the primary outcome of MT yielded no significant group × time interactions, $F(3,36) = 0.421$; $P = .739$ (Fig 2; Tables 3 and 4).

Secondary analysis of the ID yielded a significant effect of MT for task difficulty in all groups, $F(3,36) = 96.19$; $P < .001$. Post-hoc testing using Bonferroni pairwise comparisons revealed significant differences between each of the movement time scores at each of the 4 different indexes of difficulty. The MT finding for ID indicates that Fitts' Law was upheld, and participants' performance shows that both W and A of the task affected motor performance.

**Table 2.** *Lumbar Spine Range of Motion (in Degrees) Descriptive Statistics*

| | Pre-SM | Pre-NI | Post-SM | Post-NI |
|---|---|---|---|---|
| Flexion, mean (SD) | 20.9 (7.5) | 26.2 (16.0) | 24.7 (8.7) | 22.9 (13.1) |
| Extension, mean (SD) | 19.4 (8.8) | 23.3 (11.7) | 21.9 (8.1) | 20.7 (11.1) |
| Left lateral flexion, mean (SD) | 16.3 (4.0) | 18.9 (5.5) | 20.4 (8.1) | 21.0 (6.6) |
| Right lateral flexion, mean (SD) | 15.9 (3.7) | 17.9 (4.8) | 18.7 (6.5) | 20.9 (10.6) |
| Left rotation, mean (SD) | 11.3 (6.3) | 11.7 (6.2) | 25.7 (30.7) | 10.7 (10.8) |
| Right rotation, mean (SD) | 15.7 (15.5) | 10.4 (12.1) | 13.4 (11.8) | 10.3 (9.3) |

*NI*, no intervention; *SD*, standard deviation; *SM*, spinal manipulation.

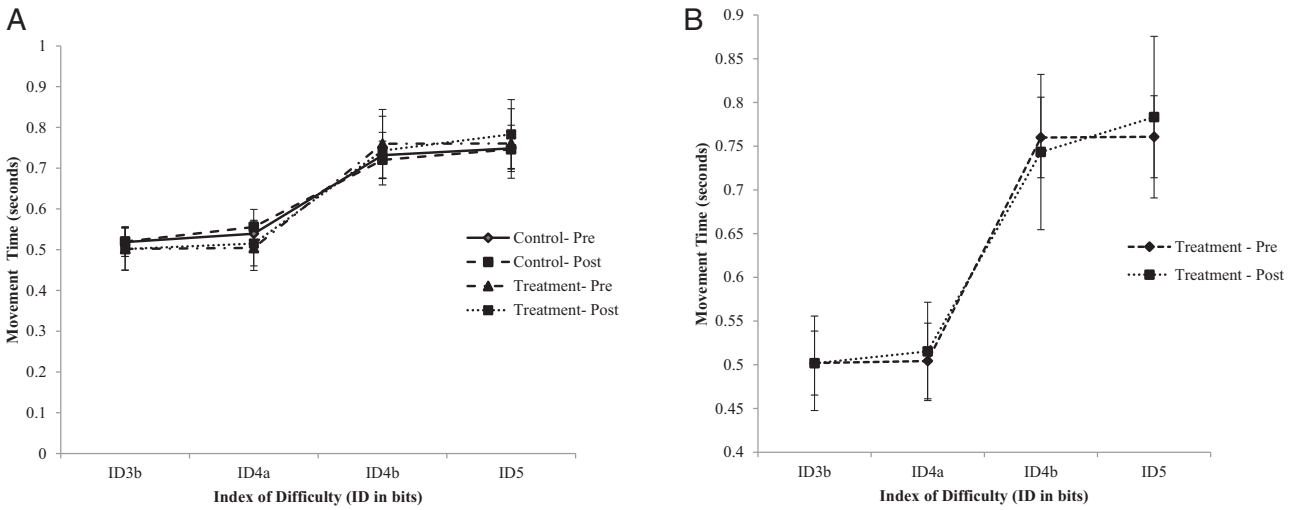


**Fig 2.** *Mean movement time by ID control and intervention groups. (A) Control and intervention groups, (B) intervention group only.* ID, *index of difficulty.*

For RT, no significant differences were found between or within groups, and no significant differences were found for the spatial endpoint pre- and postintervention.

### Kinematic Measures

Regarding kinematic measures, the analysis showed similar findings to MT because there were no significant interactions identifying between-group differences for peak velocity $F(3,36) = 0.298$; $P = .827$, time to peak velocity $F(3,36) = .190$; $P = .903$, and peak acceleration $F(3,36) = 0.252$; $P = .860$.

Secondary analysis of the ID yielded a significant effect across task difficulty for peak velocity$F(3,36) = 211.70$; $P < .001$, time to peak velocity$F(3,36) = 75.15$; $P < .001$, and peak acceleration $F(3,36) = 38.90$; $P < .001$.

Bonferroni pairwise comparisons revealed no differences beyond the gross movements that were required to attain the appropriate change in the distance required by the task, which superseded any precision movements associated with coordinated movement to targets of different sizes.

## Discussion

In this study we investigated the effect of a single SM intervention session on a lower-extremity Fitts' task in patients with degenerative LSS. Direct between-group comparisons of the primary outcome measure MT revealed no significant differences. However, all participants demonstrated movement times that were congruent with a Fitts' Law task, where MT increased linearly with ID. Upon further examination of secondary kinematic measures, it was consistently found that the amplitude of the movement had a greater impact on all participants in all conditions than the size of the target itself.

In Figure 1, we can see task difficulty combinations of the experiment. The second and third targets in the

**Table 3.** *Primary Outcome Movement Time in Seconds Between Groups and by Intervention Time*

| Comparator | Pre | Post | Change Score (Over Time) |
|---|---|---|---|
| Treatment group, mean (SD) | 0.632 (0.183) | 0.636 (0.193) | 0.004 |
| 95% CI | | | -0.201 to 0.193 |
| Control group, mean (SD) | 0.635 (0.120) | 0.636 (0.114) | 0.001 |
| 95% CI | | | -0.124 to 0.122 |
| Mean between-group differences | 0.633 (0.126) | 0.636 (0.122) | 0.003 |
| 95% CI | | | -0.095 to 0.089 |

*CI*, confidence interval; *SD*, standard deviation.

experiment have the same level of difficulty (ID = 4 bits). The overlap was designed deliberately to attribute any performance differences specifically to either movement amplitude (A) or target width (W) of the Fitts' task. By examining the third and fourth targets (IDs 4b and 5), one would expect that MT would be longer for target number 4 (ID5). For the MT data, predictions based on Fitts' Law were found. Previous research has found support for the idea that improved coordinated motor performance is an expected outcome after a single session of SM.[17,18,26,27] However, those studies did not consider an aging population with a chronic degenerative condition. It is likely that a longer course of care would be needed before performance changes could be observed in patients with a chronic condition.

Similar to MT, participants in both groups regardless of intervention showed significant changes in peak velocity (Fig 3A), time to peak velocity (Fig 3B), and peak acceleration (Fig 3C) associated with increased task difficulty. The pattern of the kinematic results also provides evidence that patients with LSS are more adversely affected by the distance to a target than its actual size. The kinematic findings potentially reflect the physical level of disability experienced by individuals with LSS. The ballistic nature of their movement initiation and execution supersedes any online corrections in limb aiming for rapid lower-extremity movements. Our results are corroborated by previous research. In a study by Passmore et al,[7] the investigators showed that patients with degenerative LSS had longer MTs compared with healthy, non-LSS individuals. Further, this difference was more prominent when moving the lower extremity in larger distances, resulting in a higher index of difficulty for the task.

The Fitts' task applied in this study can be used as an objective, performance-based assessment measure for patients with LSS, although potentially it is more useful after a course of care as opposed to a single intervention. Clinicians who provide noninvasive care for patients with LSS can use this approach to assess the level of impairment among patients, even on subtle changes that may not be detected on questionnaire-based outcome measures, or active ROM scales. Questionnaire-based outcome measures may be of limited utility in the conservative management of spine pain populations with comorbid psychological issues.[15] A strength of the Fitts' task as an assessment measure is that it is resistant to learning effects. Such resistance means it could be repeated over time, with the only measurable changes being associated with one's physical ability to do the task. Performance will either improve as a result of the intervention or natural history, or be degraded by the advancement of a disabling condition or pathology. The Fitts' task assessment measure may be of benefit for LSS patients requiring a course of conservative management or more invasive types of care as well, such as surgery or pharmaceutical trials, but future research is needed to elucidate the usefulness in such contexts.

### Limitations

As with any clinical population, there is inherent heterogeneity in the research participants. There was no chart review to investigate time since initial diagnosis or duration of symptoms. No attempt was made to modify or control possible concurrent pharmacological intervention including but not limited to type and dosage of analgesics. Subtypes of degenerative LSS (spinal level, central, or foraminal) were not controlled for or recorded by the experimenters. We simply identified potential study participants deemed at that time as nonsurgical candidates with a confirmed diagnosis of degenerative LSS. As an assessor-blind study where the experimenters collecting dependent measures were kept naïve, patients were aware of whether they received the intervention or not. No attempt was made to blind the participants owing to the challenges associated with identifying an inert placebo or appropriate sham for manual therapies including SM therapy.[21] Although no immediate adverse events were

**Table 4.** *Primary Outcome Movement Time by ID in Seconds*

| Indexes of Difficulty | Pre | Post | Change Score |
|---|---|---|---|
| ID 3 | | | |
| Treatment, mean (SD) | 0.502 (0.138) | 0.502 (0.143) | 0.000 |
| 95% CI | | | -0.147 to 0.147 |
| Control, mean (SD) | 0.519 (0.093) | 0.520 (0.097) | 0.001 |
| 95% CI | | | -0.101 to 0.099 |
| Mean between-group differences | 0.510 (0.113) | 0.511 (0.118) | 0.001 |
| 95% CI | | | -0.087 to 0.085 |
| ID 4A | | | |
| Treatment, mean (SD) | 0.504 (0.146) | 0.515 (0.149) | 0.011 |
| 95% CI | | | -0.166 to 0.144 |
| Control, mean (SD) | 0.540 (0.087) | 0.556 (0.115) | 0.016 |
| 95% CI | | | -0.123 to 0.091 |
| Mean between-group differences | 0.522 (0.117) | 0.536 (0.129) | 0.014 |
| 95% CI | | | -0.105 to 0.077 |
| ID 4B | | | |
| Treatment, mean (SD) | 0.760 (0.223) | 0.743 (0.235) | -0.017 |
| 95% CI | | | -0.223 to 0.257 |
| Control, mean (SD) | 0.732 (0.149) | 0.721 (0.123) | -0.011 |
| 95% CI | | | -0.132 to 0.154 |
| Mean between-group differences | 0.746 (0.183) | 0.732 (0.180) | -0.014 |
| 95% CI | | | -0.120 to 0.148 |
| ID 5 | | | |
| Treatment, mean (SD) | 0.761 (0.225) | 0.783 (0.245) | 0.022 |
| 95% CI | | | -0.268 to 0.224 |
| Control, mean (SD) | 0.749 (0.150) | 0.746 (0.124) | -0.003 |
| 95% CI | | | -0.141 to 0.147 |
| Mean between-group differences | 0.755 (0.184) | 0.765 (0.187) | 0.010 |
| 95% CI | | | -0.147 to 0.127 |

*CI,* confidence interval; *ID*, index of difficulty; *SD*, standard deviation.

reported, being a single-day, single-intervention trial, there was no longer-term follow-up period, which would have been needed to monitor any events. Future trials on performance measures over a course of care should include procedures for adverse event monitoring over time.

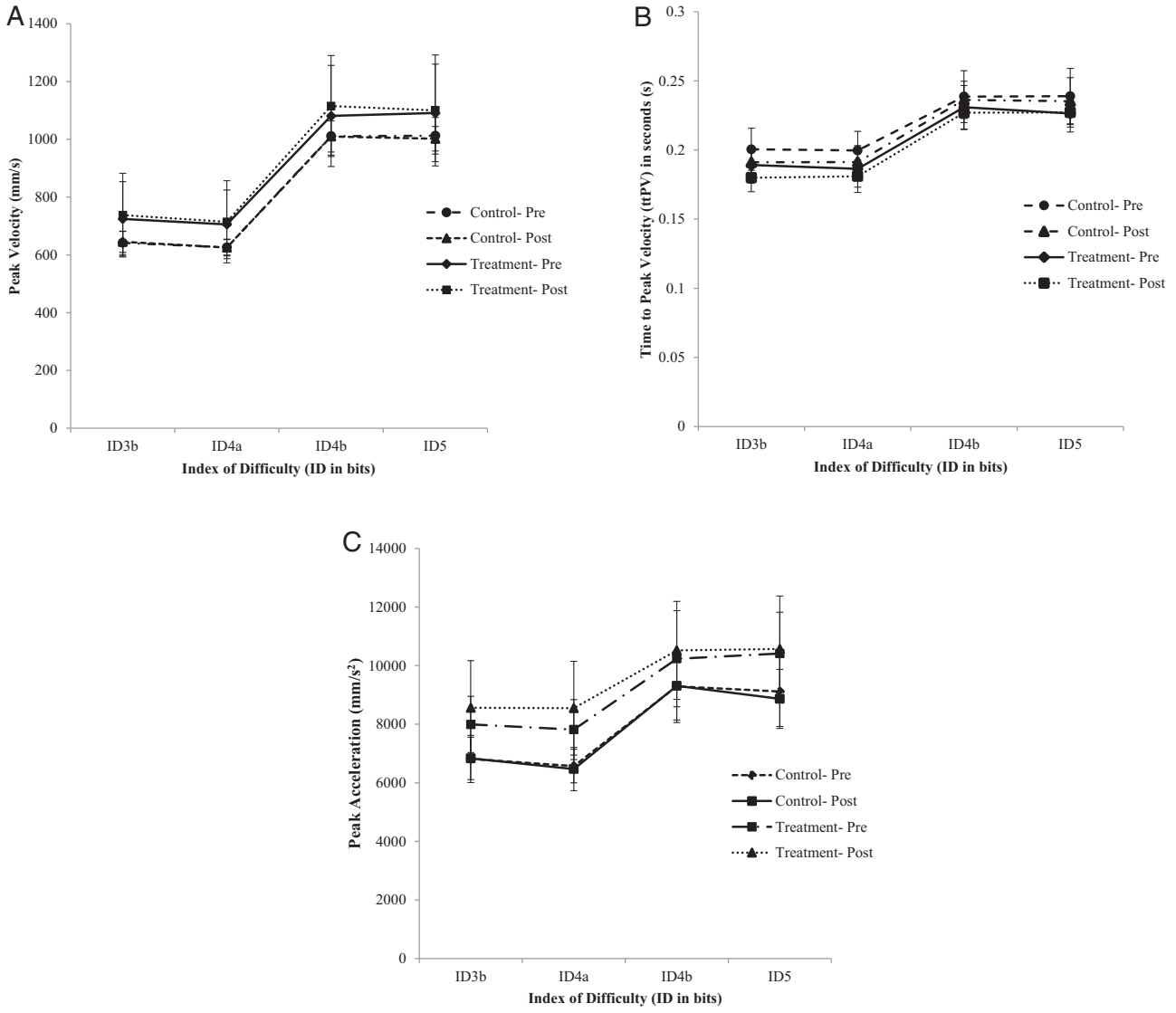


**Fig 3.** *Kinematic effects by ID. (A) Mean peak velocity, (B) mean time to peak velocity, (C) mean peak acceleration. Error bars reflect standard error of the mean.* ID, *index of difficulty.*

### Future Studies

Future research should consider the limitations described earlier and also consider sample size beyond that of a feasibility study. Regarding sample size, our study represents a preliminary investigation of the immediate effect of a single intervention of SM on patients with LSS, thus the generalizability should be interpreted with caution. Future clinical trials should consider recruiting a larger sample size. In addition, our intervention does not represent a typical course of nonoperative clinical care for LSS patients; rather, we did a single-day intervention only. Other studies should investigate the effect of SM over a course of care, which more closely reflects standard clinical practice. Future studies examining the performance-based effects of SM over a course of treatment among LSS patients are warranted.

## Conclusion

In this study, SM had no significant effect on MT performance, although the study may have been underpowered to detect a meaningful difference between groups. Fitts' Law was maintained for the lower-extremity pointing task for an LSS population. The performance-based measure provided more information about movement coordination than a simple measure of pain or ROM could. There were also no immediate changes in pain or lumbar ROM after a single SM intervention on this chronic pain population.

**Practical Applications**

- Our work provides objective evidence that people with degenerative LSS demonstrate impaired motor performance measurable using a Fitts' Law task.
- We have developed a performance-based task that could be more useful in future clinical trials examining a full course of SM care.
- For LSS patients, typically the scaling of gross movements to attain the appropriate distance to the target supersedes precision movements.

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## Contributorship Information

Concept development (provided idea for the research): S.R.P., M.G.J., C.M.G.
Design (planned the methods to generate the results): S.R.P., M.G.J., C.M.G.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): S.R.P, M.G.J., S.M.A., S.C., M.A., C.M.G.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): S.R.P., M.G.J., S.C., M.A.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): S.R.P., M.A.
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