ORIGINAL ARTICLES

THE EFFECT OF CHIROPRACTIC ADJUSTMENTS ON MOVEMENT TIME: A PILOT STUDY USING FITTS LAW

Dean L. Smith, DC, PhD,[a] Marvin J. Dainoff, PhD,[b] and Jane P. Smith, DC[c]

ABSTRACT

Objective: To investigate the effect of chiropractic adjustments on movement time using Fitts Law.

Methods: This was a prospective, randomized controlled trial. Ten patients from a private chiropractic practice participated. Participants in the treatment group received high-velocity, low-amplitude chiropractic adjustments to areas of joint dysfunction (chiropractic subluxation). A nonintervention group was used to control for improvement resulting from time and practice effects.
Movement time was measured as participants moved a cursor onto a target appearing on a computer screen. A range of target widths and target distances were used to vary the index of difficulty.

Results: All participants in the experimental group had significantly improved movement times following spinal adjustments compared with only 1 participant in the control group. The average improvement in movement time for the experimental group was 183 ms, a 9.2% improvement, whereas the average improvement in movement time for the control group was 29 ms, a 1.7% improvement. The difference (improvement) scores after the intervention were significantly greater for the chiropractic group compared with the control group as measured by a 2-tailed independent samples t test ($P < .05$).

Conclusion: The results of this study demonstrated a significant improvement in movement time with chiropractic care. These results suggest that spinal adjustments may influence motor behavior. (J Manipulative Physiol Ther 2006;29:257-266)

Key Indexing Terms: *Manipulation; Chiropractic; Motor Skills; Behavior; Fitts Law; Motor Control*

Much chiropractic research has been devoted to determining the effects of chiropractic care on various symptoms and disorders such as low back pain, neck pain, and headaches. In addition, some basic science research demonstrates that these disorders (particularly low back pain) are related to perceptual and behavioral changes in individuals ranging from reduced proprioception to changes in muscle recruitment patterns to altered kinematics.[1-7] Despite the knowledge that spinal dysfunction is associated with altered motor control, there is little evidence relating chiropractic adjustments (the term used within the profession for the use of manual force that results in correcting a chiropractic subluxation, which is defined in chiropractic as an area of joint dysfunction[8]) to changes in motor behavior (eg, coordination, movement time [MT], kinematics). Instead, there is an abundance of anecdotes (eg, "We adjust patients and they seem to move better").

Chiropractic research has looked mainly at movement control from neurophysiological and biomechanical perspectives. This research has shown that chiropractic affects several factors that influence movement control. For example, reductions in resting muscular tone (quantified by surface electromyography in prone posture) have been documented following adjustments, as have improvements in muscular strength.[9,10] In addition, reaction times to a complex mental rotation task have decreased[11] with adjustments. A recent review of the neurophysiological effects of spinal manipulation[12] identifies experimental evidence that spinal manipulation influences proprioceptive primary afferent neurons from paraspinal tissues. Spinal manipulation also affects how

[a] Private Practice of Chiropractic, Essence of Wellness Chiropractic Center, Eaton, Ohio; Visiting Faculty, Department of Physical Education, Health and Sports Studies, Miami University, Oxford, Ohio.
[b] Professor, Department of Psychology, Miami University, Oxford, Ohio.
[c] Private Practice of Chiropractic, Essence of Wellness Chiropractic Center, Eaton, Ohio.
Submit requests for reprints to: Dean L. Smith, DC, PhD, Essence of Wellness Chiropractic Center, 890 South Barron St., Eaton, OH 45320 (e-mail: *drdean@essenceofwellness.com*).

pain signals are processed, possibly by altering the central facilitated state of the spinal cord.[12] Pickar[12] also finds evidence that spinal manipulation affects several neurophysiological processes including the following: alteration of group Ia and group II mechanoreceptor discharge; sensory processing in the spinal cord (ie, central facilitation); the neuroendocrine system; and the control of skeletal muscle reflexes (ie, somatosomatic reflexes). In summary, the available biomechanical and neurophysiological data indicate that spinal manipulations can affect the motor control system.[12]

Central motor facilitation seems to be a basic, immediate neurophysiological response to chiropractic care[13,14] along with significant attenuation of α motoneuronal activity. Kinematic changes following chiropractic have also been noted in small samples,[15-17] and H-reflex activities have been reduced.[18] Preliminary findings by Smith[17] also indicate that coordination and balance changes result from chiropractic adjustments. A recent study using magnetic resonance imaging has shown that spinal adjusting produces movement at the zygapophyseal joints of the spine, thus revealing biomechanical effects of chiropractic.[19] However, spinal biomechanists[20] engaged in chiropractic research seem to be interested in first examining the effects of adjustments on a local level, leaving the global behavior of the patient open to investigation.

Research on chiropractic treatment has focused largely on the physiological and neurological processes that underlie behavior. In doing so, the profession has short-changed the investigation of goal-directed motor behaviors. This omission is important because it is at this *macroscopic* or behavioral scale of analysis that improvements in the performance of everyday activities are found, and ultimately, the value of any treatment must be assessed.

FITTS LAW AND CHIROPRACTIC

In an attempt to address these shortcomings, this experiment was designed to evaluate the usefulness of applying Fitts Law to the measurement of human MT following chiropractic adjustments. Fitts Law is a mathematical relation describing the speed-accuracy trade-off in motor skill performance. Specifically, it predicts the MT for a situation in which a person must move to a target as quickly and accurately as possible. Fitts Law is a highly successful psychomotor relation that accurately models human MT.[21] It is said,[22] "...this law has proven to be one of the most robust, highly cited, and widely adopted models to emerge from experimental psychology." This relationship is called a law because of its application across many kinds of tasks including discrete aiming movements, moving objects to insert them into a hole, moving a cursor on a screen, small finger movements under a microscope, and even throwing darts.[23] Fitts Law has also proved accurate in describing movements made by subjects of all ages, from infants to older adults.[23]
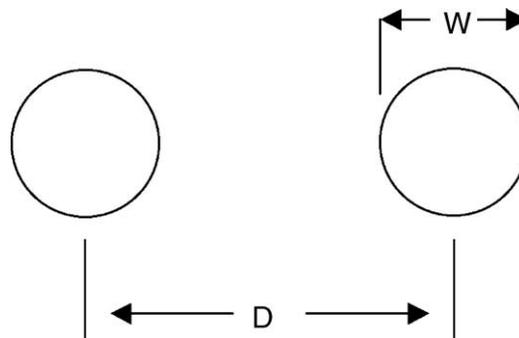
Fig 1. *The Fitts paradigm. The participant moves a cursor between 2 targets of width W separated by a distance D.*

MT is defined as the interval from the initiation of the response (eg, mouse click) to the completion of the movement (eg, subsequent mouse click)[24] and can be predicted by movement distance (D) and target width (W), as seen in Fig 1. The term $\log_2 (2D/W)$ has been called the index of difficulty (ID). Empirically, the relationship between MT and ID is linear with intercept a and slope b.[22] Targets with low ID are "easier" because either the distance is less or the target is wider. This is because less difficult tasks require less MT. Fitts Law is thus expressed by the following equation: MT = $a + b \log_2 (2D/W)$. The Fitts paradigm was initially modeled by an experimental psychologist but has been widely adopted by numerous other research fields, including kinematics, human factors, and human-computer interaction.[25]

The need to conduct this experiment comes from our limited knowledge regarding how chiropractic adjustments affect motor behavior. By measuring the MT of 2 groups of participants to different computer targets, this experiment sought to answer 2 questions:

1. Do chiropractic adjustments affect MT?
2. Is Fitts Law a useful objective paradigm to test the motor effects of chiropractic care?

We hypothesized that (*a*) each participant receiving chiropractic adjustments would have reduced MTs postadjustment and (*b*) that the treatment group would have reduced MTs compared with the control group. This 2-part hypothesis is based on studies demonstrating reductions in muscle inhibition and improved force output in both lower and upper extremity muscles after spine manipulation.[26-28] From a mechanistic view, we wanted to investigate if the adjustment might increase force production of upper extremity muscles allowing movement to become faster.

METHODS

Participants

Twelve right-handed, existing patients from the private practice of the authors (DS, JPS) and between the ages of
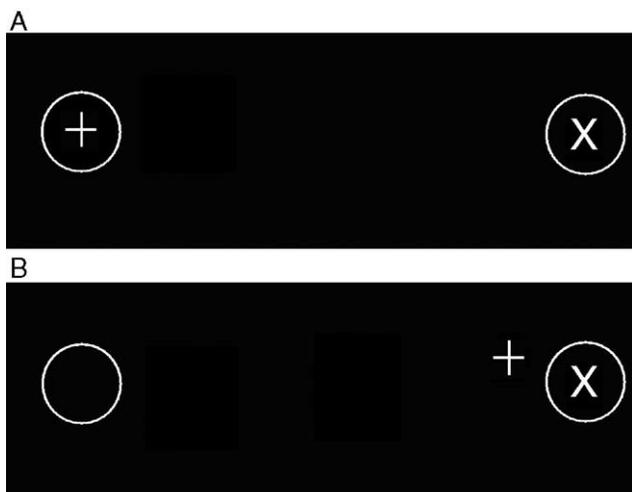
Fig 2. *The Fitts task used in this experiment. Clicking the mouse shows the crosshair pointer in 1 circle and the target (red X) in the opposite circle (A). The participant moves the cursor as fast as possible into the center of the circle with the red X, then presses the mouse button to end the trial (B).*

Fig 3. *Representation of the angular conditions used in the Fitts task. The participant moves a cursor between 2 targets of width W separated by a distance D at an angle θ.*

24 and 46 years volunteered to participate. Data from 2 participants were discarded because they had an unacceptable error rate (see below) on the Fitts Law task. Thus, 10 (6 female, 4 male) patients (mean ± SD, 33.3 ± 7 years) completed the study. All patients had been adjusted at least 4 times before data collection using the diversified technique described below. Participants were recruited through posted notices in the office as well as by email newsletters where patients were "blind carbon copied." The recruitment notice emphasized that participation was voluntary and that their participation or lack thereof in the study would by no means alter their selected course of chiropractic care or relations with the doctors.

Participants were not selected if they had a history of vestibular/inner ear dysfunction or had a history of recurrent dizziness, falling, or vertigo. Those patients not able to perform normal activities of daily living such as standing, sitting, and sit-stand activities were not included. No participant had recent trauma within the 6 months before data collection. All participants had normal or corrected to normal vision. Because of the nature of chiropractic practice and for the purposes of this study, patients were not specifically excluded because of the presence of their presenting neuromusculoskeletal problems, unless their ability to perform the computer task was impaired by their condition. There were 4 female participants (2 control, 2 experimental) and 1 male (control) participant who had minimal low back pain at the time of testing. In all cases, the pain was at or below 2 of 10 as measured by a visual analog scale. All participants stated that they were comfortable throughout the testing period. All participants read and signed an informed consent document approved by the
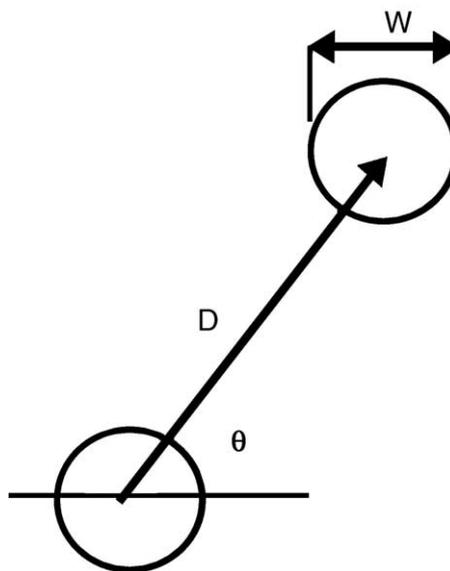
Miami University Institutional Review Board. Participants were not informed of the aims of the study.

Chiropractic Intervention

All participants in the study were given a chiropractic examination before the Fitts task to determine the location(s) of spinal dysfunction. The chiropractic examination consisted of a postural assessment and palpation of the entire spine. Specifically, the clinician used the following criteria to detect areas of spinal dysfunction: abnormal end-feel; abnormal quality of resistance to motion; and reproduction of pain, either local or referred (in symptomatic patients), or production of tenderness/pain, either local or referred in nonsymptomatic participants.[29-31]

Participants assigned to the treatment group received adjustments after completing the baseline task. The primary chiropractic technique for delivering adjustments (eg, manipulation)[8,31] was diversified technique emphasizing high-velocity, low-amplitude thrusts to vertebral segments. Chiropractors adjust nearly 72% of their patients with diversified technique, which illustrates how commonly this technique is used in practice.[32] Lumbar side-posture adjustments, supine cervical rotary (index pillar push) adjustments, and prone (bilateral thenar contact) or supine (opposite-side contact) thoracic adjustments were used.[31] Adjustments were delivered in attempt to correct any or all of the spinal subluxations that the clinician (JPS) found on that visit. This allowed the chiropractor to be very pragmatic in the delivery of care, as they would be in normal practice. The adjusting protocol in this study was consistent with the education and practice of chiropractors, emphasizing care of

Table 1. *The Fitts task*

Amplitude	Width	ID	Angles	Pairs	Replications	No. of trials
150	37.5	3	8	2	2	32
150	18.8	4	8	2	2	32
150	9.4	5	8	2	2	32
150	4.7	6	8	2	2	32
160	20.5	4	8	2	1	16
160	9.8	5	8	2	1	16
160	4.9	6	8	2	1	16
160	2.5	7	8	2	1	16
80	20.5	3	8	2	1	16
80	9.8	4	8	2	1	16
80	4.9	5	8	2	1	16
80	2.5	6	8	2	1	16

Trials completed by participants 1-4 are shown in the nonshaded area of the table. Participants 5-10 completed trials in the shaded (uppermost 4 rows) portion of the table. All participants completed 8 angle conditions, 4 width conditions, and 128 trials per block.

the entire spine and was thought to more closely approximate the "chiropractic experience" than single region or single level spinal adjusting only.

Control Intervention

As with any motor task, some improvement was expected because of learning. Because the participants had all been previously adjusted, a sham control procedure was not possible. The control group made possible the testing for MT improvement as a result of the passage of time and learning. Participants assigned to the control group rested for 4 minutes after completing the baseline task (see Design and Procedure). This was the approximate length of time it took to perform the adjustments in the treatment group.

Task

Participants were seated and given a computerized Fitts Law task. Each participant was instructed to use a mouse to move a cursor onto a circular target. The data were collected using a personal computer while sitting at arm's length distance from the monitor. A single trial consisted of moving the cursor from 1 circle to another. A mouse click began each trial. At the beginning of a trial, a crosshair pointer appeared in 1 circle, and a red X appeared in the opposite circle denoting it as the current target (Fig 2). Immediately following the initial mouse click, the participant moved the cursor to the target as fast as possible and mouse clicked within the target circle to end the trial.

Design and Procedure

MT from the initial starting position to the target was recorded during each trial by the computer. Participants were encouraged to move as fast as possible while at the same time avoiding missing the circle (error = did not mouse click within the circle). Error trials produced an audible beep to provide feedback to the participant during the experiment. Error trials were also recorded in the data file for analysis. For

each block of trials, mean MTs, MT variability, and percent of trials with error were calculated. An error rate of 5% or less on a block of trials (ie, missing the circle on ≤5% of trials) was deemed acceptable for use in this study to allow meaningful comparisons within and between participants. Error rates >5% on any block of trials constituted an unacceptably high level of error, and the data from these subjects were discarded. Patients were not explicitly told to maintain a 95% level of accuracy or greater.

The target diameter and target distance were systematically adjusted to achieve multiple different indices of difficulty that were rounded to the nearest decimal point. The Generalized Fitts Law Model Builder Version 1.1 (Guelph, Ontario, Canada)[33,34] was used to generate the stimuli and record the MTs in this experiment. For most of the subjects (subjects 5-10), all trials were conducted using the same amplitude or distance (150 mm) between targets. The program was configured to provide a paired serial-pointing task with 4 width and height conditions (37.5, 18.8, 9.4, and 4.7 mm) and 8 angle conditions (0°, 45°, 90°, 135°, 180°, 225°, 315°, and 360°) presented in random order. Fig 3 depicts a graphic representation of the angle conditions. The paired serial-pointing task consisted of 1 trial immediately followed by a second trial where the locations of the crosshair and X were reversed. This allowed the participant to move quickly back and forth between the 2 targets in a serial nature. Paired trials had identical width/height and angle conditions. Sixty-four pairs of serial trials were completed. Each width/height and angle condition pair was replicated to yield 128 trials per block (4 width/height conditions × 8 angle conditions × 2 trials per pair × 2 replications). See Table 1 for a summary of the different conditions in this experiment. Applying Fitts Law to the amplitude/width dimensions resulted in 4 indices of difficulty (ID = 6, 5, 4, and 3) within a block. Therefore, 32 trials at each ID level were performed within a block. Each block of trials lasted approximately 5 minutes.

Subjects 1-4 (2 controls, 2 experimental) completed 1 additional ID (ID = 7). This extra condition was used to

Table 2. *Mean MTs before and after chiropractic adjustments for the experimental group*

Participant	Age (y)	Sex	Presenting symptom	Total blocks	MT before adjustment (ms)	MT after adjustment (ms)	Improvement in MT (ms)	P
3	29	Male		4	1936.07	1740.08	195.99	.000
4	30	Female		3	1896.72	1781.15	115.57	.008
5	36	Female	LBP	3	2311.41	2123.69	187.73	.000
6	32	Female	LBP	3	2266.68	2067.91	198.77	.000
10	38	Male		3	2442.13	2226.98	215.15	.000
Standard error					107.89	96.48	17.35	
Mean (ms)					2170.60	1987.96	182.64	
Mean percent improvement (%)					9.17			

Note: asymptomatic patients at the time of presentation are denoted by blank spaces in the presenting symptom column.
P value from paired *t* test comparing MT before and after adjustment).

Table 3. *Mean MTs before and after rest period for the nonintervention group*

Participant	Age (y)	Sex	Presenting symptom	Total blocks	MT before rest period (ms)	MT after rest period (ms)	Improvement in MT (ms)	P
1	29	Male		4	1865.28	1841.81	23.47	.630
2	27	Female	LBP	4	1570.37	1563.84	6.53	.849
7	46	Male	LBP	3	2593.45	2424.63	168.82	.000
8	42	Female	LBP	4	2163.53	2049.20	114.33	.206
9	24	Female		3	2749.91	2917.89	−167.98	.006
Standard error					219.81	235.94	57.52	
Mean (ms)					2188.51	2159.47	29.03	
Mean percent improvement (%)					1.70			

Note: asymptomatic patients at the time of presentation are denoted by blank spaces in the presenting symptom column.

determine whether additional IDs would yield further insight into the movement complexity between the treatment group and the control group. For the first 4 participants, the program was configured to provide the same, paired serial-pointing task as for the other participants. The presentation of these paired trials was identical to the other subjects. The same 8 angle conditions (0°, 45°, 90°, 135°, 180°, 225°, 315°, and 360°) remained, but 4 different width/height conditions (20.5, 9.8, 4.9, and 2.5 mm) and 2 amplitude conditions were used (80 and 160 mm) to create the additional ID. Thirty-two trials were completed for each of the indices of difficulty 4, 5, and 6. Sixteen trials each were completed for indices of difficulty 3 and 7. Therefore, 128 trials per block were also used for these participants. See Table 1 for a complete summary of the conditions of this experiment for all participants.

Because the effect of learning this task was of consideration, all subjects performed the task until learning was deemed no longer present. Absence of a learning effect was operationally defined as nonsignificant differences in mean MTs between consecutive blocks determined by a dependent samples *t* test. Only 3 blocks of trials were necessary to curb the learning effect. Therefore, the maximum number of blocks that any participant required was 4. Once the learning effect was no longer present, the participant was randomized into either the treatment group or the control group. Two slips of paper were placed in an envelope, one with "control" written on it and the other with "chiropractic" written on it. A slip of paper was pulled from the envelope to determine group assignment for that participant. Participants did not know whether they were in the experimental group or the control group and were hence "blinded" to group assignment. Participants randomized to the control group rested for a few minutes after completing 2 consecutive nonsignificant blocks, whereas participants in the treatment group were adjusted after completing 2 nonsignificant consecutive blocks. After completing the respective intervention, participants performed 1 final block of trials to determine if the intervention improved performance on the Fitts task.
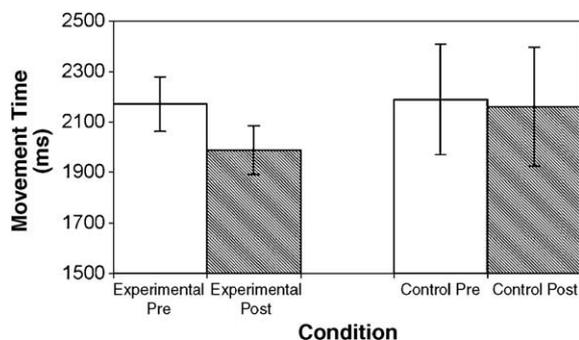
Fig 4. *Differences in group MT (mean ± SE) before and after intervention. The means for each group before intervention were not significantly different.*

Fig 5. *Differences in MT between pre- and postadjustment across ID (mean ± SE). The preadjustment scores yield a regression line with MT (ms) predicted as MT = 831.7 + 288.5 × ID. The postadjustment scores yield a regression line with MT (ms) predicted as MT = 758.1 + 268.0 × ID.*

Analysis

ID 7 for the first 4 participants did not show any large differences in mean MT or variability when compared with the other indices of difficulty. Based on these findings, it was decided that ID 7 provided no additional insight into the nature of MTs pre- or postintervention. As a result, the subsequent 6 participants did not complete ID 7 (Table 1). Because all individual means were computed as the average MT across all 128 trials in a block (eg, averaged across all ID levels), all subjects were entered into the final group analysis. Two separate sets of inferential analyses were conducted for this study. One set of analyses investigated the question of whether chiropractic significantly influenced the MT of an individual. The other set of analyses investigated the question of whether chiropractic significantly influenced the mean MT of the group of individuals receiving adjustments compared with the control group. All analyses were conducted with α equal to 0.05.

Within-Participant Analysis. The MT for each trial was the basic unit of measure in this study. For a given individual, the change in MT between 2 successive blocks of trials was compared using 2-tailed, dependent samples *t* tests. Each of the MTs for the 128 trials per block constituted the cell entries for the dependent samples *t* tests. Therefore, the degrees of freedom for all paired *t* tests was 127. The individual paired *t* test was based on pairings of identical stimulus conditions: ID, angle, and sequential location within block. These analyses were conducted to determine 2 things. First, this type of analysis revealed the point at which learning (nonsignificant differences between consecutive blocks of trials) ceased. Second, it was used to test the null hypothesis that there were no changes in mean MT for an individual following the intervention.

Group Analysis. The mean MT computed as the average across all 128 trials in a block formed the basic unit of analysis. To determine if the experimental group differed from the control group in mean MT (postintervention), we performed a 2-tailed, equal variance, independent samples *t* test on the difference scores for each group. The difference
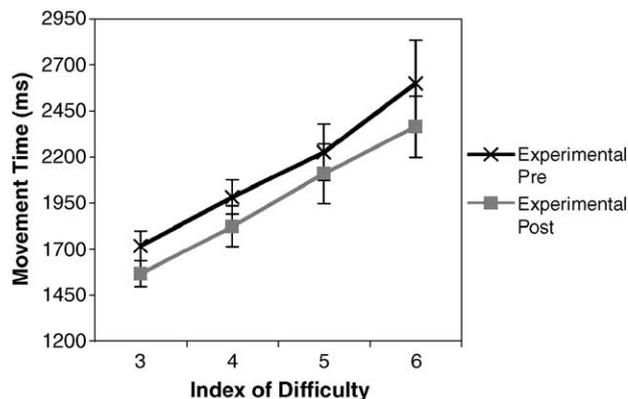
scores for each individual constituted the cell entries for the independent samples *t* test. The difference scores were achieved by subtracting the postintervention scores for an individual by the preintervention scores for the same individual (Tables 2 and 3).

RESULTS

Within-Participant Analyses

Most participants showed an improvement in MT postintervention (Tables 2 and 3). Each of the participants in the experimental group improved significantly following adjustments, whereas only 1 participant improved significantly in the control group following rest. One participant (no. 9) in the control group performed significantly worse following rest. *P* values for the dependent samples *t* tests are shown for each participant (Tables 2 and 3). These values reflect the difference in mean MT between the block of trials before intervention and the block of trials after intervention, and all have degrees of freedom equal to 127.

Group Analysis

The average reduction in MT for the experimental group was 182.64 ms, a 9.17% improvement, whereas the average reduction in MT for the control group was 29.03 ms, a 1.70% improvement. The control group had an average MT before intervention of 2188.51 ms, whereas the experimental group had an average MT of 2170.60 ms before intervention. In comparing the MTs between groups before intervention, Levene test for equality of variances was nonsignificant, indicating that equal variances should be assumed. An equal variance, 2-tailed, independent samples *t* test of preintervention MTs demonstrated no significant differences between groups ($P = .943$) (Fig 4).
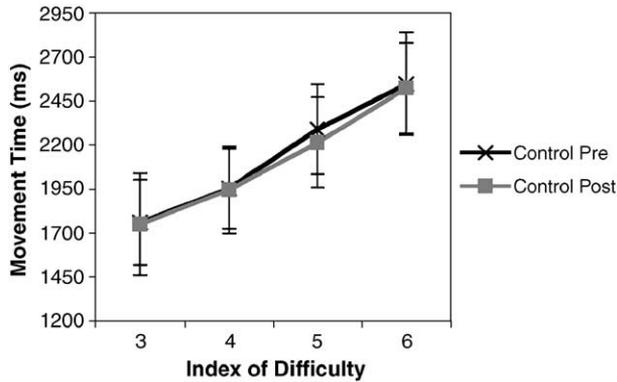
Fig 6. *Differences in MT between pre- and postcontrol across ID (mean ± SE). The precontrol scores yield a regression line with MT (ms) predicted as MT = 922.7 + 269.9 × ID. The postcontrol scores yield a regression line with MT (ms) predicted as MT = 940.0 + 259.4 × ID.*

To determine if the experimental group differed from the control group in mean MT, we performed a 2-tailed, equal variance, independent samples *t* test on the difference scores for each group. The difference scores for each participant are found in Tables 1 and 2 and are under the column labeled "improvement in MT." Levene test for equality of variances was nonsignificant for this test, indicating that equal variances should be assumed. The treatment group (mean = 182.64, SE = 17.35) had significantly improved MTs following intervention compared with the control group (mean = 29.03, SE = 57.52), $t(8) = 2.56$, $P = .034$, $d = 1.62$.

Performance across ID for the experimental group compared with the control group is presented in Figs 5 and 6. These figures demonstrate that the relationship between MT and ID is linear as Fitts Law predicts. The treatment group shows greater improvement in MT at each ID compared with the control group.

DISCUSSION

The data demonstrate motor changes following chiropractic adjustments. The overall results can be divided into 2 primary findings. First, a single session of chiropractic care was shown to significantly improve the MT of all individuals receiving spinal adjustments. Second, the experimental group of patients was shown to have significantly improved MTs compared with the nonintervention group. Given that not all patients received adjustments to the same spinal segments, the traditional statistical data analysis using averaging across patients was also supplemented with analysis of individual performance. This strategy was deemed necessary because averaging across patients can be misleading,[35] particularly when patients were not all homogeneous with respect to symptoms and location of spinal dysfunction.

MT is one of the most important variables influencing the way we control our movements.[36] MT is used a great deal in skills research as a result of its overall external validity in these practical settings (eg, time to run 100 m).[24] At the elite sport level, where milliseconds can mean the difference between winning and losing, even small changes in MT can have a large effect. For instance, differences between the personal best times of the top sprinters in the world can differ by approximately 1% (ie, Greene 9.79 s, Bailey 9.84 s, Christie 9.87 s). Thus, even minor changes in MT could have important implications for athletic endeavors.[37] Although some (albeit small) improvement in MT was observed in the control group, the significantly greater improvement in motor performance for the experimental group (9.2%) suggests that chiropractic adjustments may benefit motor performance beyond the effects of learning or practice.

Generally, as MT increases (ie, becomes slower), there is greater potential for more feedback loops to contribute to the originally intended action.[36] More specifically, MT dictates the type of feedback corrections that are possible and the relative contribution of different types of modifications (ie, M1, M2, and M3 responses) to the original movement commands.[36] Because MT can contribute to dynamic balance through feedback correction, it may have implications not only for athletics but also for rehabilitation professionals. For example, it has been suggested that MT is an objective, simple, and reliable tool to evaluate bradykinesia in Parkinson disease.[38] Furthermore, MT improvement following medical intervention[38,39] has been related to Parkinson disease severity. The clinical significance of MT improvement following adjustments was not addressed in this study. However, given the potential contribution of improved MT to motor control and clinical status, further research is recommended.

The chiropractic and osteopathic literature have for the most part found short-term neurophysiological and/or biomechanical effects of adjustments/manipulations. Although an acute benefit of treatment suggests that more may be better, it is not clear from this study how long the motor improvements may have lasted for the individual. The purpose of this study was simply to detect if acute motor benefits were achievable in chiropractic patients. It is interesting, however, that all patients in this study had been adjusted at least 4 times previously and still experienced such acute, significant improvements. Only recently have studies been conducted that examine the dose-response relationship of chiropractic care to clinical outcome.[40-42] Results from these studies show clinical improvements with increased frequency of care and maintenance. In light of these dose-response studies and the findings from this study (despite the small number of subjects), it seems prudent to further investigate the potential long-term motor control benefits in chiropractic patients.

The present experiment investigated the effects of chiropractic on the psychomotor domain of human perform-

ance using Fitts Law. Fitts Law is an extremely robust model of motor behavior that takes into account the speed-accuracy trade-off in motor skill performance. Empirically, the relationship between MT and ID is linear. Figs 5 and 6 confirm this linear relationship for both groups of participants and hence provide evidence that Fitts Law may be a useful model for examining the motor effects of spinal adjusting. We did not explicitly compare the effects of chiropractic at the different IDs. However, Fitts Law would be an ideal model to answer the question, "Do chiropractic adjustments have a differential effect on the complexity of movements?" To gain more insight into the mechanisms of action, future research could be directed at determining which IDs are most improved with manual care.

MT is generated at a macroscopic or behavioral level of analysis.[24] Behavior refers to those actions of an individual that are directly observable.[43] For example, human posture is considered to be a behavior that is observable and quantifiable.[44] A number of factors contribute to the emergence of human motor behavior. It is generally recognized that movement arises from the interaction of the person and environment demanding such processes as perception, cognition, and action.[23] Given these factors, it is logical that for chiropractic adjustments to affect MT, spinal adjustments must affect perception, cognition, or action, or each of these components in combination.

Kelly et al[11] provide an excellent discussion of the potential influence of chiropractic on cognition. These authors[11] used a mental rotation reaction time paradigm to demonstrate significant improvement in a complex reaction-time task after an upper cervical adjustment compared to rest. They found evidence that the adjustment had specific effects on cognitive processing as distinct from improving MT. This was partly demonstrated by the fact that there was no significant change in a simple reaction-time task that required only minimal cortical processing. However, both the Kelly et al study[11] and the present study have limitations in isolating the effect of chiropractic to either cognition or motor control because these tasks required both cognitive and motor function. It is proposed that to better test the effects of chiropractic on cognition will require different tasks. These tasks will ideally not rely on the ability to respond quickly using the motor system (eg, reaction times or MTs). Tests of long-term memory and attention satisfy these criteria because ample time may be given for cognitive processing, and the motor response is not directly related to accomplishing the task.

As for the effects of spinal adjusting or manipulation on motor control, relatively few studies are reported. Of the studies that are done, many have focused on a microlevel of analysis including neurophysiological approaches.[12] The behavioral studies that exist have concentrated on muscular strength and muscular inhibition. For example, Suter et al[26-28] have demonstrated reductions in muscle inhibition and improved force output in both lower and upper

extremity muscles after spine manipulation. Several studies investigating muscular strength following spinal adjusting/manipulation have shown improvements in strength, although a few studies show no effect.[10,45] More recently, perceptual-motor investigations have been reported. Head repositioning accuracy is becoming a commonly accepted means of documenting proprioceptively mediated declines in motor control as well as demonstrating improved control. Rogers[46] found that subjects receiving manipulation demonstrated a 41% improvement in mean scores for head repositioning skill. In addition, Enebo[47] found that cervical spine joint manipulation improved overall movement accuracy and overall movement variability but did not improve participant individual variability on a cervical spine rotation task. Thus, the results of Rogers and Enebo[46,47] suggest that spinal manipulation could improve proprioceptive functioning.

The potential of some type of treatment being applied (eg, expectation of improvement) having a psychosomatic or mechanical effect on patients, thereby, unintentionally encouraging them to move in an improved manner, was a concern in the design of this study. Wells et al[48] provide a discussion of this topic. Because an effective sham adjustment does not exist for manipulation, we decided to include a manual chiropractic examination including postural analysis and palpation to detect areas of spinal subluxation. This examination was performed on all study participants so that both groups experienced similar physical contact before any data collection. Performance of the physical examination was intended to reduce the possible effects of touch alone on MT outcomes.

Another concern in the design of this study was the small sample size. However, 2 studies from the osteopathic literature supported our approach to dealing with the control group and small sample size concerns.[48,49] These studies demonstrated that (*a*) significant treatment effects can be found in small sample sizes with manual care; (*b*) manipulation can influence movement, even with a small sample size; and (*c*) a structural examination can be a component of a viable control condition that can produce differences in outcome with respect to manual treatment. In addition, the extremely large effect size (Cohen $d = 1.62$) obtained in the present experiment is suggestive that chiropractic adjustments have robust effects on movement and hence a large sample size may not be required to demonstrate the effect.

CONCLUSION

The data demonstrate that a single session of chiropractic spinal adjustments may lead to a significant improvement in MT in patients that had previously been adjusted. The duration of these motor control effects is unknown. An assessment of individual performance found that all

participants in the experimental group improved significantly. An assessment of group performance found that the treatment group experienced significantly reduced MTs compared with the control group and that this effect was large. Future research is needed to determine the components of motor control that are affected by chiropractic adjustments, their mechanisms of action, and how long the effects last.

Practical Applications

- Individuals receiving chiropractic adjustments experienced immediate and statistically significant improvements in MT.
- MTs were significantly improved for the chiropractic group compared with the control group.
- Clinicians and researchers should consider the effects of spinal adjustments on motor behavior.

REFERENCES

1. Reeves NP, Cholewicki J, Milner TE. Muscle reflex classification of low-back pain. J Electromyogr Kinesiol 2005;15: 53-60.
2. Davis KG, Seol H. Injury-induced kinematic compensations within the lower back: impact of non-lower back injuries. Ergonomics 2005;48:135-49.
3. Burnett AF, Cornelius MW, Dankaerts W, O'Sullivan PB. Spinal kinematics and trunk muscle activity in cyclists: a comparison between healthy controls and non-specific chronic low back pain subjects—a pilot investigation. Man Ther 2004;9:211-9.
4. Ferguson SA, Marras WS, Burr DL, Davis KG, Gupta P. Differences in motor recruitment and resulting kinematics between low back pain patients and asymptomatic participants during lifting exertions. Clin Biomech 2004;19:992-9.
5. Moseley GL, Nicholas MK, Hodges PW. Does anticipation of back pain predispose to back trouble? Brain 2004; 127:2339-47.
6. Lehman GJ. Biomechanical assessments of lumbar spinal function. How low back pain sufferers differ from normals. Implications for outcome measures research. Part I: kinematic assessments of lumbar function. J Manipulative Physiol Ther 2004;27:57-62.
7. van Dieen JH, Selen LPJ, Cholewicki J. Trunk muscle activation in low-back pain patients, an analysis of the literature. J Electromyogr Kinesiol 2003;13:333-51.
8. Hawk C, Long CR, Reiter R, Davis SD, CJ A, Evans R. Issues in planning a placebo-controlled trial of manual methods: results of a pilot study. J Altern Complement Med 2002;8:21-32.
9. Shambaugh P. Changes in electrical activity in muscles resulting from chiropractic adjustment: a pilot study. J Manipulative Physiol Ther 1987;10:300-4.
10. Smith DL, Cox RH. Muscular strength and chiropractic: theoretical mechanisms and health implications. J Vertebral Sublux Res 1999-2000;3:1-13.
11. Kelly DD, Murphy BA, Backhouse DP. Use of a mental rotation reaction time paradigm to measure the effects of upper cervical adjustments on cortical processing: a pilot study. J Manipulative Physiol Ther 2000;23:246-51.
12. Pickar JG. Neurophysiological effects of spinal manipulation. Spine J 2002;2:357-71.
13. Dishman JD, Ball KA, Burke J. Central motor excitability changes after spinal manipulation: a transcranial magnetic stimulation study. J Manipulative Physiol Ther 2002;25:1-9.
14. Dishman JD, Bulbulian R. Comparison of effects of spinal manipulation and massage on motoneuron excitability. Electromyogr Clin Neurophysiol 2001;41:97-106.
15. Lehman GJ, McGill SM. The influence of a chiropractic manipulation on lumbar kinematics and electromyography during simple and complex tasks: a case study. J Manipulative Physiol Ther 1999;22:576-81.
16. Lehman GJ, McGill SM. Spinal manipulation causes variable spine kinematic and trunk muscle electromyographic responses. Clin Biomech 2001;16:293-9.
17. Smith DL. Postural dynamics following chiropractic adjustment: preliminary findings. In: Smart LJ, editor. International Society for Ecological Psychology. Oxford (OH): Miami University; p. 3.
18. Murphy BA, Dawson NJ, Slack JR. Sacroiliac joint manipulation decreases the H-reflex. Electromyogr Clin Neurophysiol 1995;35:87-94.
19. Cramer GD, Gregorson DM, Knudsen JT, Hubbard BB, Ustas LM, Cantu JA. The effects of side-posture positioning and adjusting on the lumbar z joints: a randomized controlled trial with sixty-four subjects. Spine 2002;27:2459-66.
20. Herzog W. The mechanical, neuromuscular, and physiologic effects produced by spinal manipulation. In: Herzog W, editor. Clinical biomechanics of spinal manipulation. New York: Churchill Livingstone; 2000. p. 191-207.
21. Fitts PM. The information capacity of the human motor system in controlling the amplitude of movement. J Exp Psychol 1954;47:381-91.
22. MacKenzie IS. Fitts' law as a research and design tool in human-computer interaction. Hum-Comput Interact 1992;7: 91-139.
23. Shumway-Cook A, Woollacott M. Motor control: theory and applications. Philadelphia: Lippincott Williams & Wilkins; 2001.
24. Schmidt RA, Lee TD. Motor control and learning a behavioral emphasis. Champaign (Ill): Human Kinetics; 2005.
25. Soukoreff RW, MacKenzie IS. Towards a standard for pointing device evaluation, perspectives on 27 years of Fitts' law research in HCI. Int J Human-Comput Stud 2004;61: 751-89.
26. Suter E, McMorland G, Herzog W, Bray R. Conservative lower back treatment reduces inhibition in knee extensor muscles: a randomized controlled trial. J Manipulative Physiol Ther 2000;23:76-80.
27. Suter E, McMorland G. Decrease in elbow flexor inhibition after cervical spine manipulation in patients with chronic neck pain. Clin Biomech 2002;17:541-4.

28. Suter E, McMorland G, Herzog W, Bray R. Decrease in quadriceps inhibition after sacroiliac joint manipulation in patients with anterior knee pain. J Manipulative Physiol Ther 1999;22:149-53.

29. Gatterman MI. Foundations of chiropractic: subluxation. St. Louis (Mo): Mosby; 1995.

30. Leach RA. The chiropractic theories: a textbook of scientific research. 4th ed. Baltimore (Md): Lippincott, Williams & Wilkins; 2004.

31. Peterson DH, Bergmann TF. Chiropractic technique: principles and procedures. 2nd ed. St. Louis (Mo): Mosby; 2002.

32. Christensen M, Kollasch MW. Job analysis of chiropractic. Greeley (Colo): National Board of Chiropractic Examiners; 2005.

33. Soukereff RW, MacKenzie IS. Generalized Fitts' Law model builder version 1.1. Guelph (Ontario, Canada): the authors. C. [software on the internet]. 1995—[cited 2000 Jun 14]. Available from ftp://snowhite.cis.uoguelph.ca/pub/fitts-law/gflmb.

34. Soukoreff RW, MacKenzie IS. Generalized Fitts' Law model builder. In: Katz IR, Mack R, Marks L, Rosson MB, Nielsen J, editors. Companion proceedings of the ACM conference on human factors in computing systems—CHI'95. New York: ACM; 1995. p. 113-4.

35. Vicente KJ, Torenvliet GL. The earth is spherical ($P < .05$): alternative methods of statistical inference. Theor Issues Ergon Sci 2000;1:248-71.

36. Schmidt RA, Wrisberg CA. Motor learning and performance: a problem based learning approach. 3rd ed. Champaign (Ill): Human Kinetics; 2004.

37. Behm DG, Bambury A, Cahill F, Power K. Effect of acute static stretching on force, balance, reaction time, and movement time. Med Sci Sports Exerc 2004;36:1397-402.

38. Zappia M, Montesanti R, Colao R, Quattrone A. Usefulness of movement time in the assessment of Parkinson's disease. J Neurol 1994;241:543-50.

39. Jankovic J, Ben-Arie L, Schwartz K, Chen K, Khan M, Lai EC, et al. Movement and reaction times and fine coordination tasks following pallidotomy. Mov Disord 1999;14:57-62.

40. Haas M, Groupp E, Aickin M, Fairweather A, Ganger B, Attwood M, et al. Dose response for chiropractic care of chronic cervicogenic headache and associated neck pain: a randomized pilot study. J Manipulative Physiol Ther 2004;27:547-53.

41. Haas M, Groupp E, Kraemer DF. Dose-response for chiropractic care of chronic low back pain. Spine J 2004;4:574-83.

42. Descarreaux M, Blouin JS, Drolet M, Papadimitriou S, Teasdale N. Efficacy of preventive spinal manipulation for chronic low-back pain and related disabilities: a preliminary study. J Manipulative Physiol Ther 2004;27:509-14.

43. Santrock JW. Psychology. Updated 7th ed. Boston: McGraw Hill; 2005.

44. Smart LJ, Smith DL. Postural dynamics: clinical and empirical implications. J Manipulative Physiol Ther 2001;24:340-9.

45. Bonci A, Ratliff R. Strength modulation of the biceps brachii muscles immediately following a single manipulation of the C4/5 intervertebral motor unit in healthy subjects: preliminary report. Am J Chiropr Med 1990;3:14-8.

46. Rogers RG. The effects of spinal manipulation on cervical kinesthesia in patients with chronic neck pain: a pilot study. J Manipulative Physiol Ther 1997;20:80-5.

47. Enebo B. The effect of cervical spine manipulation on motor control in healthy individuals: a pilot study. Chiropr J Aust 2003;33:93-7.

48. Wells MR, Gaintinoto S, D'Agate D, Areman BA, Fazzini EA, Dowling D, et al. Standard osteopathic treatment acutely improves gait performance in patients with Parkinson's disease. J Am Osteopath Assoc 1999;99:92-8.

49. Noll DR, Shores J, Bryman PN, Masterson EV. Adjunctive osteopathic manipulative treatment in the elderly hospitalized with pneumonia: a pilot study. J Am Osteopath Assoc 1999;99:143-52.