# KINETIC ANALYSIS OF EXPERTISE IN SPINAL MANIPULATIVE THERAPY USING AN INSTRUMENTED MANIKIN

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**ABSTRACT**

*Objective: The goals of this study were to measure the kinetic profile of thrust in different groups of subjects with various levels of expertise and to quantify general coordination while performing thoracic spine manipulation.*

*Participants: A total of 43 students and chiropractors from the Chiropractic Department of the Université du Québec à Trois-Rivières participated in this study.*

*Methods: Participants were asked to complete ten consecutive thoracic spine manipulations on an instrumented manikin. Peak force, preload force, time to peak force, time to peak force variability, peak force variability, rate of force production and unloading time were compared between groups. Hand-body delay obtained by calculating the temporal lag between the onset of unloading and the onset of peak force application was also compared between groups.*

*Results: No group difference was observed for the peak force, peak force variability and preload force variables. However, group differences were present for variables like time to peak force, time to peak force variability, rate of force production, unloading time and hand-body delay.*

*Conclusion: This study demonstrates clear differences between groups of subjects with different levels of expertise in thoracic spine manipulation. This study also demonstrates the usefulness of a simple, instrumented manikin to analyze spinal manipulation and identify important parameters related to expertise. (J Chiropr Med 2005;4:53–60)*

**Key Indexing Terms:** Manipulation, Spinal; Professional Competence; Task Performance and Analysis; Education

## INTRODUCTION

There has been considerable progress in the development of new skills in spinal adjustment in the last century. A large number of colleges and universities throughout the world are now teaching various forms of spinal adjustment. Over the years, many different techniques of spinal manipulative therapy (SMT) have been used to give patients the most effective treatment.[1,2] Chiropractic students learn to perform these adjustment techniques during their training years. The process of learning implies an increased capability of performing skilfully in a particular situation.[3] Thus, it implies that the practice goal for the learner in this task is to improve motor coordination and force application through practice to reach an adequate level of motor proficiency.

Overall, the goal of SMT is to apply force and moment with specific parameters of direction, amplitude and speed to a joint to deliver a biomechanical and/or neurological effect in the affected tissues.[4–6] To acquire these psychomotor skills, students usually practice on human subjects to emulate the upcoming professional demands of their practice. Thus, understanding how students learn such techniques could potentially improve teaching methods and allow young trainees to deploy specific procedures that are the trademark of expertise.

A review of the chiropractic literature reveals a dearth of research in motor learning.[4,7,8] However, in a recent paper, Scaringe, et al[9] reviewed most of

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the work on the applications of motor learning principles (knowledge of performance, knowledge of results, guidance hypothesis) relating to teaching chiropractic adjustments. Two lines of research are of particular interest to us: one of them refers to training devices to improve performance and retention of various chiropractic skills. Young et al[4] demonstrated the pertinence and effectiveness of a cervical manikin for the skill development of students practicing these procedures. In a blind review process, the examiners found no significant differences between the students who learned with the manikin alone and those who learned with the established approach on fellow students. Scaringe et al[9] also used a simulator in a thrusting maneuver (unilateral hypothenar transverse procedure) with two predetermined force levels. Their findings suggest that once again the simulator is a valuable tool to improve learning of complex motor skills.

The other line of research in the chiropractic learning literature relates to quantifying differences in predefined biomechanical parameters of SMT by novice and practicing care providers. Cohen et al[10] designed their study to identify kinetic parameters that would show statistical differences between newly-trained and experienced care providers. For all kinetic measures (preload, upper rise rate, thrust force), the mean values were higher in the experienced group, but did not reach the significance level because of large between-subject variability. Recently, Triano et al[11] addressed the issue of developing skilled performance in lumbar spine manipulation. The goal of their study was two-fold: it was designed first to quantify elements of performance in a specific spinal manipulation (diversified mamillary-push procedure); and, second to test a learning strategy that combined rehearsal and quantitative feedback from an instrument measuring the application of axial forces against specific resistance levels. The subjects were divided into two experimental groups, one with standard training versus the other with standard as well as prescribed training with a specific aid. Both groups were tested on three separate occasions at intervals of three months. The results revealed significant differences between the performance of the specific aid compared to the standard training group, particularly for preload, sagittal and lateral bend moments. These data were interpreted as supporting the use of training aids to enhance performance and improve learning. Some questions have been raised concerning the learning effects in this study.[12,13] The targets for skill progression remain to be determined and are of great importance in the development of pedagogical tools that will improve the SMT training of chiropractic students.

To perform SMT adequately, one must learn to control various force parameters, but also master overall body coordination to improve SMT efficiency.[2,10,14] To address these issues, the goals of this study are to measure the kinetic profile of thrust in different groups of subjects with various levels of expertise and to quantify general coordination while performing thoracic spine manipulation. The main hypothesis of this study was that the experienced subjects will perform this SMT faster and with less variability compared to the inexperienced subjects.

## METHODS

### Subjects

A total of 43 students and chiropractors from the Chiropractic Department of the Université du Québec à Trois-Rivières (26.5 years, 25 men and 18 women) participated in this study. Four experimental groups were formed on the basis of experience in using SMT: second year students (group 1), fourth year students (group 2), final year interns (group 3), and chiropractors with at least five years of clinical practice (group 4). Two groups (second and fourth year students) had experience limited to patient and chiropractor positioning during SMT, whereas the two other groups had respectively nine months and 13.2 (6.3) years of clinical experience. Subject characteristics for each group are presented in Table 1.

### Apparatus and Procedure

A manikin used to teach cardiopulmonary reanimation was modified and instrumented with a spring to emulate the resistance offered by a thoracic spine.[1] Figure 1 illustrates the experimental set-up that simulates a thoracic posterior to anterior spinal manipulation made on a prone-positioned patient. A strain gauge (Statham, Model UL 400, Oxnard, CA) was installed at the top of a spring that replicated the movement and resistance of the rib cage. The strain gauge was used for the recording of vertical forces applied by subjects on the contact point. To simulate the typical absolute movement of thoracic vertebra undergoing SMT, the manikin was modified to limit posterior to anterior movement to approximately 5 mm. This was done by mounting

**TABLE 1**
**SUBJECT CHARACTERISTICS FOR EACH GROUP; MEAN (SD)**

| | GROUP 1 | GROUP 2 | GROUP 3 | GROUP 4 |
|---|---|---|---|---|
| MEAN AGE (YEARS) | 21.2 (1.3) | 23.0 (1.0) | 24.1 (1.7) | 39 (5.5) |
| SEX | 5 MEN | 6 MEN | 6 MEN | 8 MEN |
| | 6 WOMEN | 6 WOMEN | 4 WOMEN | 2 WOMEN |
| HEIGHT (M) | 1.73 (0.1) | 1.72 (0.1) | 1.70 (0.1) | 1.77 (0.1) |
| WEIGHT (KG) | 68.7 (10.8) | 68.5 (13.7) | 66.2 (6.3) | 88.7 (19.2) |

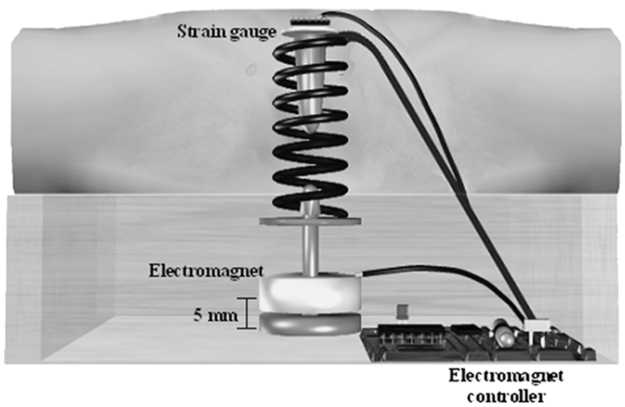


*Figure 1. Illustration of the instrumented manikin used to perform thoracic spine manipulation.*

an electromagnet at the base of the spring. The electromagnet was controlled by a variable current, which allowed the experimenter to modulate the level of maximal resistance offered by the spring. For this study, the resistive force was set to 475 N, slightly over the mean force normally applied in a typical thoracic spine manipulation generating audible release.[15,16] Once this specified force level (475 N, measured on the strain gauge) was achieved by the subject, the electromagnet turned off while the force was continuously recorded. As a result, unloading of the spring and movement of the manikin torso surface simulated articular release characterizing vertebral joint cavitation.

For the experimental session, subjects were asked to complete ten consecutive thoracic spine manipulations on the manikin with a right-handed pisiform contact. This technique is called prone unilateral hypothenar transverse adjustment.[2] Participants were asked to use a posterior to anterior force vector without any other force component. The experimenters read the specific requirements of the task and answered questions before the practice trials. All subjects were specifically asked to complete their spinal manipulations with the minimum force required to obtain electromagnet release (475 N). All subjects completed three practice trials to gauge the level of resistance produced by the electromagnet. The practice trials were not recorded. They performed ten experimental trials without any feedback concerning their performance. During the experimental session, they stood on a force plate (AMTI, OR6–5, Watertown, MA) and used body positioning of their choice as long as they stayed on the force plate.

### Data Analysis

For every trial, force applied to the manikin and vertical force from the force plate were recorded at a sampling rate of 600 Hz for 3 seconds. Force applied to the manikin and vertical force plate signals were filtered with a second-order Butterworth filter (7-Hz low-pass cut-off frequency). The following dependent variables were obtained from these two signals: onset of force, peak force applied, preload force and onset of unloading measured from the force plate. These variables were analyzed for each trial and every subject using private software (Analyse, Laval University). To determine unloading onset and onset of force, a moving algorithm was used. Following this, the data were then visually inspected to exclude any outlying data.

From these data, time to peak force, time to peak force variability, peak force variability, rate of force production and unloading time measured from the force plate were extracted and averaged for each subject. Time to peak force variability and peak force variability represents the average individual between trial variability (SD). Finally, hand-body delay was obtained by calculating the temporal lag between the onset of unloading and the onset of peak force application. When a subject makes a small amplitude downward movement (trunk or knee flexion), there is a negative acceleration of the center of mass and thus, for a short period of time, the vertical ground reaction force is less then the body weight. Until the subject applies forces on the manikin this unloading represents body motion towards the force plate. The hand body delay variable was chosen to evaluate general coordination during SMT.

All dependent variables were found to be normally distributed and therefore submitted to one-way ANOVA (group factor). Since only interns and chiropractors had a regular practice of the thrust component of spinal manipulation, all dependent variables were also submitted to another one-way ANOVA (experience factor) where the two inexperienced groups of students were merged to form one group, while the chiropractors and interns were regrouped to form a second group. This analysis tested the effect of clinical experience (ie, practicing or not practicing the thrust) When a main effect of group was observed, *post hoc* comparisons were performed by Tukey tests. For all analyses, statistical significance was set at $p < 0.05$.

**RESULTS**

Because the number of men and women were different in each group, ANOVA excluded the possibility of a confounding gender effect. For all dependent variables, ANOVA yielded no significant gender effect ($p > 0.05$). When the four groups were compared, significant group differences were observed for unloading time and hand-body delay (temporal lag between onset of unloading and onset of force application). The unloading time and the temporal lag between onset of unloading and onset of force application significantly decreased with experience (Fig 2). For unloading time, *post hoc* analyses revealed a significant difference between second year students and chiropractors and a significant difference between fourth year students and chiropractors. For hand-body delay, *post hoc* analyses revealed a significant difference between second year students and chiropractors. Table 2 presents the data for all dependent variables in all four groups.

When compared on the basis of clinical experience (groups 1–2 versus groups 3–4), significant experience differences were observed for time to peak force, time to peak force variability and rate of force production. Noticeably, significant experience differences were present for unloading time and hand-body delay. Figure 3 illustrates the mean and variability of ten trials for applied force and force plate data for one inexperienced subject (a) and (b) one experienced subject. These two subjects were chosen because they clearly illustrate the differences

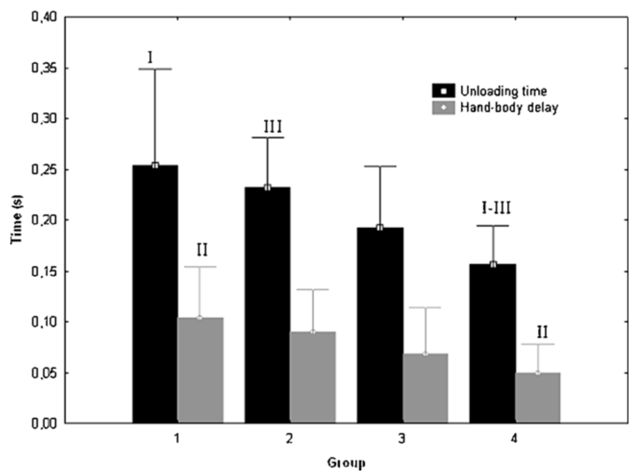


*Figure 2. Mean (SD) unloading time and hand-body delay for the four different levels of expertise. For groups 1 and 4 (second year students and chiropractors), the differences in unloading time (I) and hand-body delay (II) were significant. Also, the difference between group 2 and 4 (fourth year students and chiropractors) for unloading time (III) was significant.*

observed in unloading time, time to peak force and hand-body delay between the two groups.

Subjects without clinical experience showed longer time to peak force values, increased time to peak force variability and a smaller mean rate of force production. All these differences were statistically significant and are reported in Table 3. Figure 4 illustrates the time to peak force and rate of force production for both the inexperienced and experienced combined groups. No significant group or experience effect was noted for peak force, preload force, and peak force variability ($p > 0.05$, see Table 3).

**DISCUSSION**

In past years, clinicians and researchers have conducted a number of studies designed to characterize and describe the kinetics of high-velocity, low-amplitude spinal manipulation. Commonly, peak force, preload force, time to peak force and rate of force production are variables used to describe spinal manipulations in the scientific literature.[10,11,16] In a previous study, Cohen et al[10] hypothesized that, for these variables, differences should exist between novice and experienced manipulators. However, they were unable to identify statistically significant differences between the two groups. The objective of the present work was to quantify the

**TABLE 2**
**MEAN (SD) DEPENDENT VARIABLE VALUES FOR ALL GROUPS**

| | GROUP 1 | GROUP 2 | GROUP 3 | GROUP 4 | *P* VALUES |
|---|---|---|---|---|---|
| PEAK FORCE (N) | 570 (27) | 569 (26) | 594 (29) | 544 (29) | *P* = 0.675 |
| PEAK FORCE VARIABILITY (N) | 53 (6) | 41 (6) | 45 (6) | 44 (6) | *P* = 0.4 |
| PRELOAD (N) | 31 (20) | 41 (19) | 77 (21) | 57 (21) | *P* = 0.122 |
| TIME TO PEAK FORCE (MS) | 171 (10) | 159 (10) | 136 (11) | 140 (11) | *P* = 0.075 |
| TIME TO PEAK FORCE VARIABILITY (MS) | 19 (2) | 15 (2) | 8 (2) | 8 (2) | *P* = 0.051 |
| RATE OF FORCE PRODUCTION (N/S) | 3485 (279) | 3684 (267) | 4487 (292) | 4217 (292) | *P* = 0.092 |
| UNLOADING TIME (MS) | 253 (20) | 231 (19) | 191 (20) | 152 (20) | *P* = 0.007* |
| HAND-BODY DELAY (MS) | 104 (13) | 90 (12) | 68 (14) | 50 (14) | *P* = 0.028* |

* SIGNIFICANT DIFFERENCES.

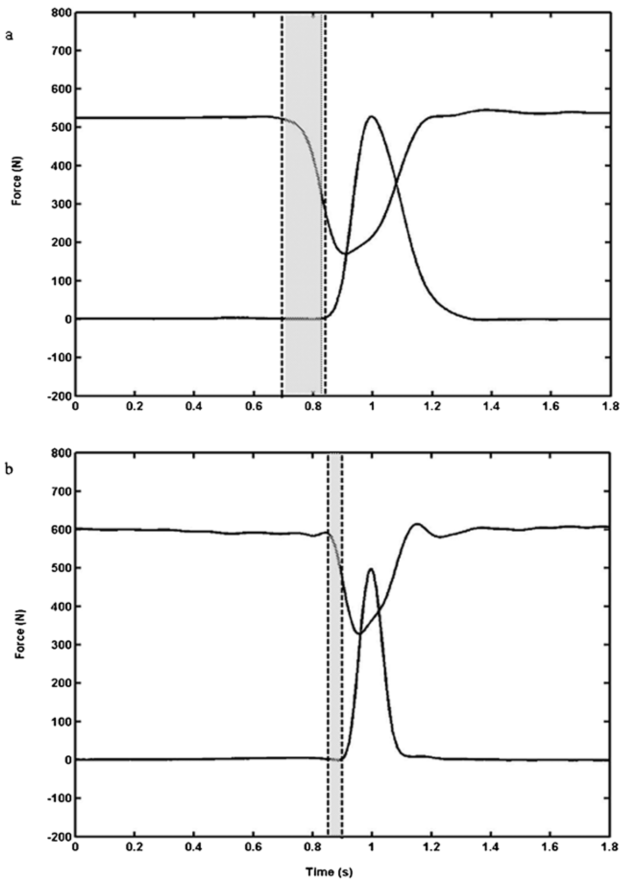


*Figure 3. Mean and variability of ten trials for applied force and force plate data for (a) one inexperienced subject (group 2) and (b) one experienced subject (chiropractor). The top line of each graph is the force plate signal, and the bottom line the force applied on the manikin. The shaded area represents the hand-body delay.*

kinetic profile of thrust in inexperienced and experienced manipulators using a manikin.

Manikins are used to teach physical procedures in various biomedical professions. However, only one study evaluated such a tool to improve the skills of chiropractic students.[4] The authors showed that students practicing cervical spine manipulations with a manikin were as adept as others practicing on their colleagues. In the present study, a great deal of attention was devoted to developing a manikin that simulated the resistance offered by the thoracic spine. Such a model is essential to place participants in a clinically, relevant situation, while keeping the mechanical properties and subjects constant throughout the trials. In our study, mean peak force, rate of force production and time to peak force observed for experienced subjects were similar to the values obtained when performing SMT on human subjects.[10,11,16] This suggests that our manikin adequately emulated the resistance offered by a human thoracic spine.

Motor learning of fast, simple movement has been studied extensively in the past.[17–19] Generally, decreases in movement time and variability of movement parameters are taken as good indicators of motor learning.[20] In the present experiment, two types of dependent variables were analyzed to determine the effects of experience on performance during thoracic spine manipulation. A first group of variables characterized motor performance of the subjects on the basis of force amplitude. This group of variables included peak force and peak force variability as well as preload force. A second group of variables determined the temporal characteristics of SMT: time to peak force, time to peak force variability, rate of force production, unloading time, and hand-body delay.

The control of force and its variability are at the heart of several motor control models aimed at understanding skillful behavior.[14,21] When a subject attempts to produce a given target force repeatedly, the between-trial variability of the force-time curves

**TABLE 3**
**MEAN (SD) DEPENDENT VARIABLE VALUES OF COMBINED GROUPS**

| | GROUPS 1–2 | GROUPS 3–4 | P VALUES |
|---|---|---|---|
| PEAK FORCE (N) | 569.5 (18.7) | 569.4 (20.1) | P = 0.998 |
| PEAK FORCE VARIABILITY (N) | 46.8 (4.2) | 44.7 (4.5) | P = 0.735 |
| PRELOAD (N) | 36.3 (13.3) | 67.2 (14.3) | P = 0.122 |
| TIME TO PEAK FORCE (MS) | 166 (7) | 139 (7) | P = 0.012* |
| TIME TO PEAK FORCE VARIABILITY (MS) | 17 (3) | 8 (3) | P = 0.007* |
| RATE OF FORCE PRODUCTION (N/S) | 3589 (192) | 4217 (206) | P = 0.032* |
| UNLOADING TIME (MS) | 242 (14) | 174 (14) | P = 0.001* |
| HAND-BODY DELAY (MS) | 97 (9) | 59 (9) | P = 0.006* |

* SIGNIFICANT DIFFERENCES.

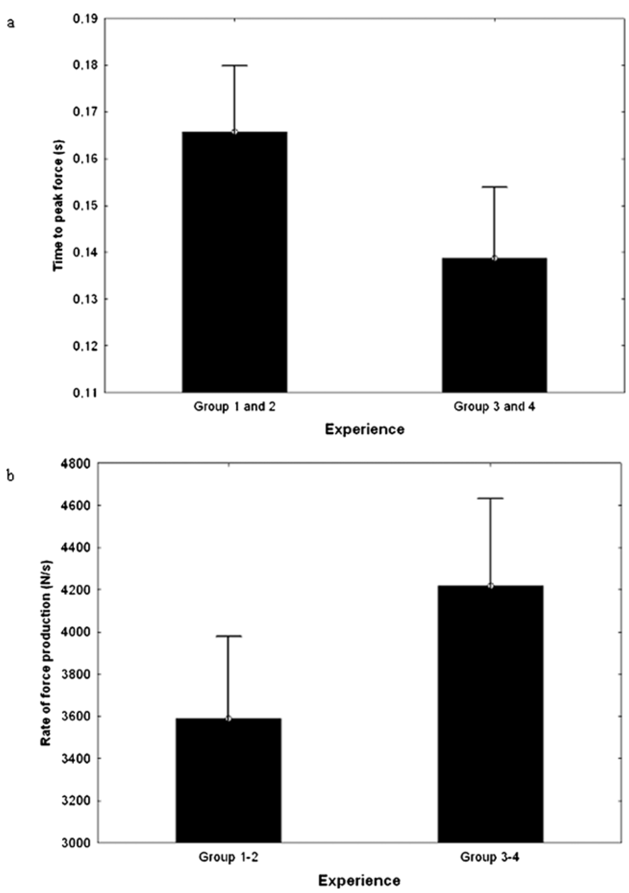


*Figure 4. Time to peak force (a) and rate of force production (b) for inexperienced and experienced subjects.*

is often taken as a critical determinant of performance. In the present study, no group differences were observed for force amplitude characteristics. Peak force, within and between subjects variability were similar for all levels of expertise, indicating that these kinetic parameters are easily acquired by both inexperienced and experienced manipulators. This result is not to surprising since a prone-thoracic manipulation is a relatively simple movement in terms of force application. The peak force needs to be applied with a quick rise and fall over time in one direction. Gordon and Ghez[21] have shown that, over a short period of learning in a simple isometric task, there is a significant decrease of peak force variability (less than 100 trials). It can be hypothesized that for more complex SMTs (side posture lumbar and pelvic manipulation) the level of expertise would influence the peak force variability.

Preload force is defined as the quasi-static load applied to the segment to be manipulated in the same direction as the intended load of manipulation. Its purpose is to reduce the elastic damping of the SMT force through the compression of soft tissues and the movement of joints through the available range of motion.[10] Some authors have suggested that preload force could be one of the variables changing with experience.[10,11] Cohen et al[10] observed higher preload values in a group of experienced chiropractors compared to a group of inexperienced students. Triano et al[11] reported an increase in preload force after a specific training program that included feedback on preload force. No group differences were noted for preload values in our study. During our experiment, subjects were asked to perform ten spinal manipulations with the minimal force needed to release the electromagnet. The absence of a significant group difference for preload force in our study could be attributed to a lack of precise preload instructions given to subjects during the experiment. Future experiments investigating the impact of learning should include precise instructions regarding preload application.

Regarding the temporal characteristics of SMT, our data indicate that subjects with clinical experience demonstrated lower time to peak force values and higher rates of force production while performing thoracic spine manipulation. A significant group difference was also observed for time to peak force variability which doubled for inexperienced subjects.

Cohen et al[10] found a similar difference in the rate of force production between newly-trained and experienced clinicians, but their results were not statistically significant. In another study where chiropractic students participated in a training program, Triano et al[11] noted an increased rate of force production. They reported a decrease of thrust phase duration for only one force component (flexion) after training. These results do not allow us to clearly understand the effects of practice on thrust phase duration.

From a biomechanical point of view, applying the same amount of force while increasing the speed of the spinal manipulation will augment the stiffness of the targeted joint. Gal et al[22] proposed that slower manipulations create greater relative movement within the functional spinal region than faster procedures. Even if more studies are warranted to understand the precise biomechanical effects of slower versus faster manipulative procedures, it can be assumed that with higher rates of force production less amplitude will be needed to manipulate a single segment.

The SMT in this experiment is a multi-joint movement that requires the subject to coordinate weight transfer to deliver fast and precise force on a limited area of the spine. Overall, the results suggest that with regular clinical experience (practice) there is improvement in performance. One of the significant changes observed between inexperienced and experienced subjects relates to the timing of force application and is manifested by a significant decrease in time to peak force, unloading time and hand-body delay. These changes are particularly interesting because they are related to the basic task requirements of SMT and clearly distinguish expertise level of the manipulators. This is also the case when learning sports skills in gymnastics or weight lifting where subjects improve timing and increase their consistency in performance outcome, that is, a decrease in within subject variability and refinement of performance or progressive inhibition of unwanted movements with expertise.[23,24]

Similar results are reported for all types of throwing movements that require weight transfer.[25–27] In fact, skillful throwing is recognized by an increase in the speed of object release velocity that is directly related to the timing of weight transfer in various experimental and natural settings. These novice and expert differences in timing suggest that it is an important variable when learning SMT. Further studies are needed to understand how the manipulative skills are acquired in inexperienced students.

## CONCLUSIONS

This study demonstrates differences between groups of subjects with different levels of expertise in thoracic spine manipulation. The requirements of the task are complex, since subjects must learn to use large muscle groups in a precise and coordinated fashion to apply thrust in an effective manner. Distinctive features between experienced and inexperienced subjects are significant and revealing in identifying parameters of expertise. During their training years, chiropractic students learn to execute spinal manipulations faster, with less variability, and in a more coordinated fashion. This study also demonstrates the usefulness of a simple, instrumented manikin to analyze spinal manipulation and identify important parameters related to expertise.

Complete kinematic analysis could allow us to better understand the coordination principles implied in learning SMT and determine precisely the body segments involved in the movement preceding the thrust. Future studies should investigate the role of knowledge of results and knowledge of performance that could be important in developing pedagogical strategies to enhance the transfer of learning in chiropractic students.

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