EDUCATION RESEARCH SERVICE

ORIGINAL ARTICLE

Learning spinal manipulation: *Gender and expertise differences in biomechanical parameters, accuracy, and variability**

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Objective: The purpose of this study was to investigate gender differences and expertise effects on biomechanical parameters as well as force accuracy and variability for students learning spinal manipulation.
Methods: A total of 137 fourth- and fifth-year students were recruited for the study. Biomechanical parameters (preload, time to peak force, peak force, rate of force), as well as accuracy and variability of thoracic spine manipulation performance, were evaluated during 5 consecutive trials using a force-sensing table and a target force of 450 N. Gender, expertise differences on biomechanical parameters, as well as constant, variable, and absolute error were assessed using 2-way analysis of variance.
Results: Analyses showed significant gender differences for several biomechanical parameters, as well as significant gender differences in accuracy and variability. Although women showed lower time to peak force and rate of force values, they were more precise and showed less variability than men when performing thoracic spine manipulations. Students with clinical expertise (fifth-year students) used less force and were more precise.
Conclusion: Our results showed that gender differences in spinal manipulation performance exist and that these differences seem to be mainly explained by alternative motor strategies. To develop gender-specific teaching methods, future studies should explore why men and women approach spinal manipulation tasks differently.

Key Indexing Terms: Chiropractic; Learning; Motor Control; Spinal Manipulation.

J Chiropr Educ 2019;33(1):1–7 DOI 10.7899/JCE-18-7

INTRODUCTION

Chiropractic is one of the leading manual therapy professions, which is both practiced and taught all around the world.[1] Although every chiropractic program is unique, most of them follow standardized requirements as suggested by the Councils on Chiropractic Education International. One of the core competencies as defined by the councils is that the chiropractor must be able to "Perform effective adjustive, manual and/or manipulative procedures with appropriate modification of treatment parameters to accommodate the particular needs of the patient and their health status."[2] According to Beliveau et al,[1] despite a broad choice of therapeutics modalities available to chiropractors, 79% of them choose spinal manipulation (SM) as the main treatment tool for their patients.[1] Although specific action mechanisms of SM remain to be determined, SM is often chosen by clinicians to improve spine mobility and can be defined as a thrust of high velocity and low amplitude (HVLA) applied with a specific direction.[3]

Over the past decades, several instrumented devices have been introduced in education to record objective biomechanical parameters (preload, time to peak force, peak force, rate of force) of SM students. Indeed, one group developed an apparatus that can be used to simulate a thoracic spine prone manipulation,[4] whereas another developed a force-sensing table (FST) able to record force-time profiles of several SM procedures.[5] From a biomechanical standpoint, SM is usually described using parameters that characterize its force-time profile, such as preload force, time to peak force, peak force, and rate of force application.[3,6] From a motor control standpoint, SM

*This paper was selected as a 2018 Association of Chiropractic Colleges – Research Agenda Conference Prize Winning Paper – Award funded by the National Board of Chiropractic Examiners.

can be described as a motor task involving an open loop mode of control. Indeed, rapid movements (less than 150 milliseconds) require a specific set of prior instructions to be performed, as they cannot be modified during execution.[7] Sensory information commonly available about the environment and the ongoing task cannot be processed rapidly enough to correct rapid movements such as SM. As described by Schmidt and Lee,[7] in a motor task such as SM, targeting a force should be considered as a "speed-accuracy trade-off" for which, as we move more rapidly, we become less accurate. Thus, the performance measures represent the degree to which the target was not achieved, a measure of error per se.[7] Studies that have explored both biomechanical and motor learning of SM describe differences between expert and novice, and clearly highlight the learning steps that students go through during their training years.[4,8]

Lately, to include recent scientific evidence, several chiropractic programs have integrated physical training and SM motor learning approaches to improve students' motor skills and confidence, as well as patient safety. However, chiropractic SM technique teaching and overall educational strategies should be tailored to meet not only the specific nature of this task, but also trainees' characteristics and specificities, such as gender, to provide relevant feedback to diverse populations of students.

In the last decades, studies exploring gender differences in motor control and learning investigated gender-based learner performances in both cognitive and manual tasks. Gender differences have been studied in the very early age and throughout childhood, adolescence, and adulthood. For example, Junaid and Fellowes[9] showed, using the Movement Assessment Battery for Children Test (a norm-referenced test of motor impairment), that boys (aged 7–8) are better at balls skills, whereas girls (aged 7–8) have better manual dexterity. Another study conducted by Rohr[10] showed that during a computer pointing task, men have shorter movement times, whereas women are more accurate during a similar computer pointing task. Unfortunately, data regarding gender differences in SM motor control and learning are scarce, and considering the growing number of women attending chiropractic schools, the purpose of this study was to investigate expertise and gender differences regarding SM performance.

Consequently, the main objective of this study was to determine if expertise and gender differences, as well as possible interactions, can be observed in SM biomechanical parameters, accuracy, and variability of students learning SM using a force-reproduction task.

METHODS

Participants

A total of 137 students were recruited to participate in the study (64 fourth-year students and 73 fifth-year students). Of these 137 students, 94 women and 43 men were recruited. Informed written consent was obtained from each participant according to the ethics certificate delivered by the Comité éthique Institut Franco-Européen de Chiropraxie (certification number: CE 2017-08-25).

The project evaluated SM parameters of fourth- and fifth-year chiropractic students at the 2 Institut Franco-Européen de Chiropraxie campuses. All participants had completed the chiropractic technique training according to the school curriculum, but students in the fifth year had also completed 1 year of clinical training in the outpatient clinic. Participants were excluded if they presented any pain or disability that would limit their capacity to perform SM on the day of testing.

Procedures

In a first phase, a familiarization period consisting of 3 SMs was conducted. Participants were instructed to perform SM as accurately as possible, targeting a peak force of 450 N. All participants were asked to perform a posterior-to-anterior thoracic SM with HVLA using a double thenar push technique. This technique was explained to the participants by the instructors before the first training session. While the students were performing their SMs, the instructors provided verbal and visual feedback (SM force-time profile).

Following the familiarization phase, a first block of 5 SMs was performed by the participants with a peak target force of 450 N and without feedback. All SMs were performed on a manikin (H.A.M. series; CMCC, Toronto, Ontario, Canada) made of a plastic spine and high-density foam padding that permitted anteroposterior compression of the thorax and for which skeletal landmarks were palpable through the foam. This instrument has been used in previous SM learning studies.[5,8,11]

Instruments and Measurements

A treatment table (Leander 900 Z Series; Leader Health Technologies Corporation, Port Orchard, WA) with an imbedded force plate (AMTI, Watertown, MA) was used to measure the input force for each SM. The imbedded force plate can reliably assess forces and moments in 3 dimensions with high sensitivity ($\mu V/[V*N] = 0.08$), low crosstalk ($\pm 0.20\%$), excellent accuracy ($\pm 0.25\%$), and long-term stability. This FST can estimate the loads transmitted during the HVLA manipulation. Forces transmitted to the table can be analyzed in an x-y-z coordinate system using custom-made software (MATLAB; MathWorks, Natick, MA).[12]

Force-time signals obtained during the assessment were analyzed to quantify relevant SM biomechanical parameters for each trial. The preload force (N) is the amount of force applied prior to the thrust, peak force (N) is the maximal force applied during the thrust, time to peak force (millisecond) is the time needed to reach peak force, whereas rate of force application (N/s) is the ratio between peak force and time to peak force. The constant error (CE), the absolute error (AE), and the variable error (VE) were calculated for each participant considering a 450-N peak-force target. CE represents the positive or negative difference (amount and direction of deviation) between the peak force reached and the peak force targeted. AE represents the absolute deviation, regardless of direction, between participants' results and the targeted peak force (ie, participants' accuracy). VE represents the participants'

Table 1 - Total Sample and Group Characteristics

	All Participants	Fourth-Year Group, $n = 64$	Fifth-Year Group, $n = 73$
Age, y, mean (±SD)	23.8 (±2.70)	22.9 (±1.97)	24.6 (±2.99)
Female/Male, *n*	94/43	43/20	51/23

consistency; it was defined as the absolute value obtained by subtracting the peak force reached during each trial to the participant's mean peak force during the corresponding assessment block.

Statistical Analysis

Descriptive statistics were used to present the overall sample characteristics. Normality of data sets was verified by visual inspection and the Shapiro-Wilks test. The force-time profiles (peak force, preload force, time to peak force, rate of force application, and drop in preload force) for each trial, as well as the CE, AE, and VE data, were independently subjected to a 2-way analysis of variance factors assessing main expertise and gender as well as a possible expertise × gender interaction effect. Post hoc analyses were performed using a Tukey test. All statistical analyses were computed with statistical software 10 (Statistica; Statsoft, Tulsa, OK), and the level of significance was set to $p = .05$.

RESULTS

Participants

All variables were found to be normally distributed and have homogeneous variances. Baseline characteristics of all participants are presented in Table 1.

Expertise Effects

Analyses revealed a main effect of expertise for the peak force and rate of force application as students in the fifth-year group produced lower mean peak forces [$F(1, 133) = 4.1464$, $p = .04371$] and lower mean rate of force applications [$F(1, 133) = 7.3031$, $p = .00778$].

A main expertise effect was also observed for the mean CE [$F(1, 133) = 4.1464$, $p = .04371$] and mean AE [$F(1, 133) = 5.1026$, $p = .02552$]. Mean (confidence interval [CI] 95%) values are presented in Figure 1.

Gender Effects

Mean (SD) values of men and women for all SM variables are presented in Table 2 and illustrated in Figure 2. The analyses yielded a main effect of gender for several biomechanical parameters. Indeed, time to peak force [$F(1, 133) = 18.844$, $p = .00003$] and peak-force mean values [$F(1, 133) = 19.387$, $p = .00002$] were significantly lower in women.

A main effect of gender was also observed for the accuracy and variability of SM trials, as significant gender differences were present for the CE and AE (Table 1). Women tended to have lower mean CEs [$F(1, 133) = 19{,}387$, $p = .00002$] and VEs [$F(1, 133) = 10.133$, $p = .00181$] than men.

The analyses did not yield interaction effect for any of the SM variables (all $p > .05$).

DISCUSSION

Previous studies on SM manipulation learning reported distinction between experts and novices regarding biomechanical parameters in the delivery of SM.[4,13] This study is, to our knowledge, the first to focus on both expertise and gender differences in SM performance in a group of chiropractic students.

Expertise Effect

The current results showed that fifth-year students were using less force than fourth-year students. While doing so, fifth-year students were also more precise, as indicated by lower CEs and AEs. The fourth-year students with less expertise might have performed the task using the stereotypical motor pattern developed during their training (ie, according to what they learned during technical training) at the expense of the task-specific force target instructions. These results confirm those of previous studies that showed that by the end of their training, chiropractic students reduce SM peak force and adopt rates of force applications that are similar to those of experienced clinicians.[4,8,13,14] These results also suggest, as previously noted, that while gaining expertise, learners significantly reduce trial-to-trial variability and increase accuracy.[4]

Gender Effect

Men and women have many physical, biological, or anatomical differences that, for most of them, arise during growth.[15] According to Kimura et al.,[13] gender differences result from human evolution and natural selection. The proposed theory suggests that men perform better in force/speed tasks, while women fare better in cognitive tasks such as finger taping or targeting tasks.[13] Studies have reported gender differences in speed/force tasks, and as described by Gutnik et al,[16] when asked to perform a single, jerk-like movement, men are better than women with a faster speed of performance.[16–18] Our data show that, in the context of the study and when instructed to perform a force-reproduction task using a specific and constant force target, women reduce SM time to peak force (speed) to increase accuracy. On the other hand, men completed the task faster but with less accuracy than women. The reason why instructions seem to have been interpreted differently by men and women remains to be studied. However, these 2 distinct behaviors can be described and interpreted using the well-known Fitts' law applicable to rapid pointing movements, which stipulates that when an individual attempts to perform a given motor

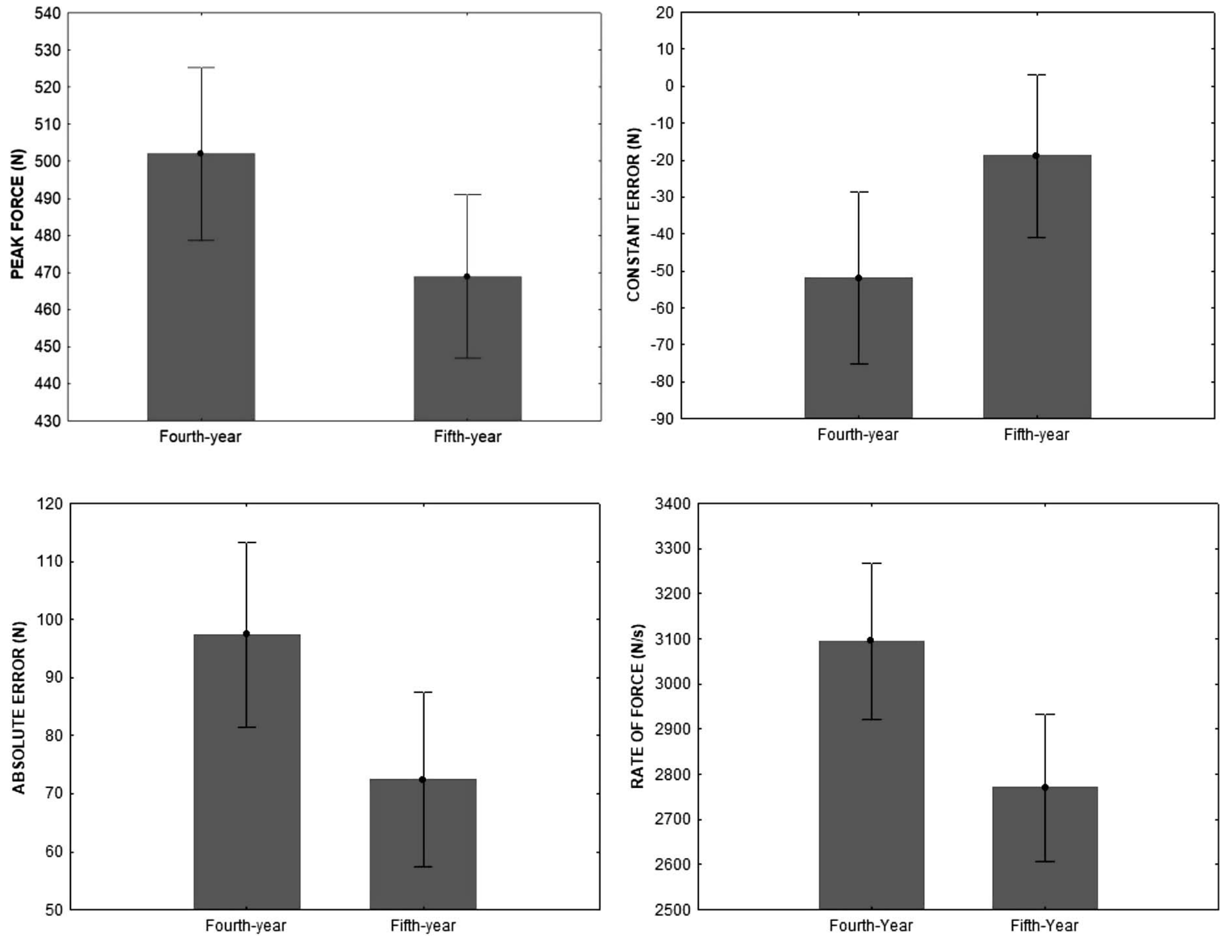

Figure 1 - Mean (CI 95%) group values for each of the following variables: rate of force application, peak force, AE, and CE.

task more quickly, the individual will typically do it less accurately.[19] Although our results clearly highlight the "speed-accuracy trade-off" phenomenon, it does not explain why women tend to reduce speed to be more accurate. However, there is other evidence that men and women address rapid motor task challenges differently.[10,20] While women and men seem to perform similarly in low-speed tasks, when speed increases, women tend to focus on the target at the expense of speed, while men do the opposite.[10,20]

The higher level of accuracy observed in women could also be linked to the lower forces produced. According to the impulse-variability theory, the variability of force impulses generates variability in limb movement and overall accuracy.[7] If more force is used in a given task (eg, SM force target task), greater variability in SM force-time profile is expected. Reducing forces and increasing time to peak force reduce within-participant variability in peak forces, leading to increased accuracy.

Again, why would women seem to reduce times to peak and peak forces and focus on accuracy? Why would men direct their focus of attention on the global performance of a theoretical successful thrust while neglecting instructions to target a specific force? Studies suggest that the effect of

Table 2 - Mean Values of All Biomechanical Parameters and Errors Variables for Both Groups (Fourth and Fifth Year) and Genders

	Fourth Year (SD)		Fifth Year (SD)	
Variables	Women	Men	Women	Men
Preload force (N)	138.61 (47.94)	149.30 (57.71)	136.98 (45.72)	165.225 (59.72)
Time to peak force (ms)	0.123 (0.013)	0.113 (0,.020)	0.126 (0.020)	0.109 (0.013)
Peak force (N)	467.65 (79.45)	536.27 (144.44)	431.79 (66.95)	504.27 (78.63)
Rate of force application (N/s)	2699.56 (543.59)	3489.76 (1012.66)	2381.49 (495.72)	3151.89 (729.36)
CE (N)	−17.65 (79.45)	−86.27 (144.44)	18.21 (66.95)	−54.27 (78.63)
AE (N)	67.15 (48.38)	127.64 (109.20)	62.25 (39.20)	80.58 (57.32)
VE (N)	24.14 (11.96)	37.68 (28.40)	28.93 (16.61)	36.08 (16.36)

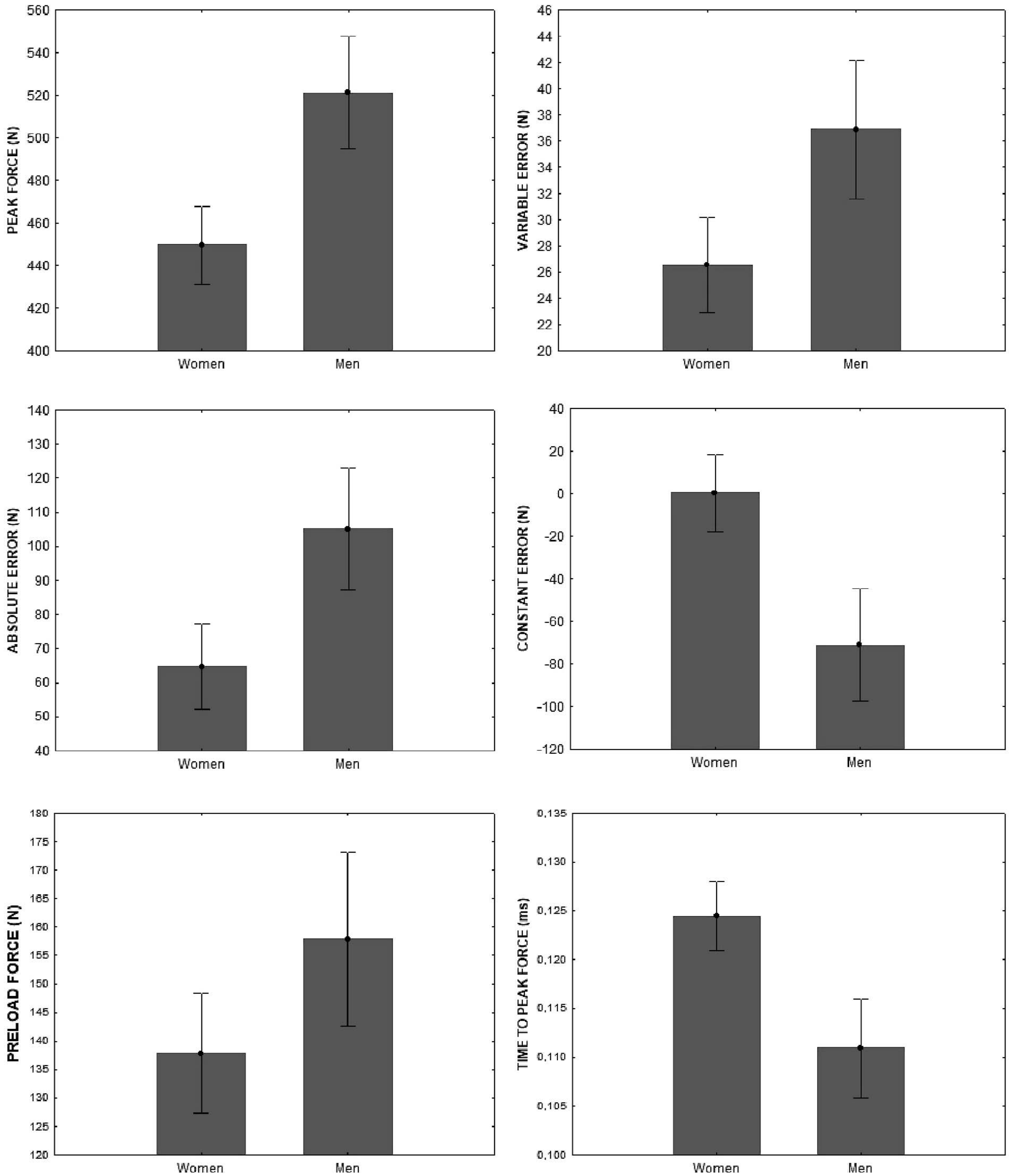

Figure 2 - Mean (CI 95%) gender values for each of the following variables: peak force, VE, AE, CE, preload force, and time to peak force.

attentional focus on instructions could be modulated by individual differences and preferences, but to our knowledge gender preferences have not been investigated.[21] Future studies should investigate how women and men improve SM skills according to various teaching approaches and strategies.

Limitations

The study was conducted at 2 different campuses. Although there were no differences in baseline characteristics of participants from each campus, differences in setup and study flow might have generated experimental biases. Instructions were standardized to limit such biases, but questions or discussions between participants and researchers may have been different from one site to another. Other variables such as physical activity participation and chiropractic-training hours outside of the school may potentially have influenced the results. From a training perspective, this study clearly highlights the need for alternative SM technique training strategies as both expertise and gender influence performance. Individually tailored training programs and frequent assessment of performance should be considered to fast-track SM motor learning before students enter clinical training with patients. Given the lack of evidence regarding the influence of SM biomechanical parameters on clinical responses, this study, however, does not inform us on the clinical significance of the gender and expertise difference observed in SM force-time profiles.

CONCLUSIONS

The goal of this study was to evaluate how gender and expertise can affect SM motor performance. The results confirm that SM performance increases with training years. Such improvement is characterized by increased accuracy and reduced variability during a SM force-reproduction task. The study also showed that gender differences in SM performance exist and that these differences seem to be mainly explained by alternative motor strategies (focusing on accuracy vs focusing on speed of execution). In order to develop gender-specific teaching methods, future studies should explore why men and women approach SM tasks differently.

FUNDING AND CONFLICTS OF INTEREST

This study was funded by the Institut Franco-Européen de Chiropraxie and the Université du Québec à Trois-Rivières Unité de recherche internationale en santé musculosquelettique. The funders had no role in study design, data collection, analysis, data interpretation, or writing of the article.

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Concept development: AL, MD, YA, MP, FBC. Design: AL, MD, YA, MP, FBC. Supervision: AL, MD, YA, MP, FBC. Data collection/processing: AL, MD, YA, MP, FBC. Analysis/interpretation: AL, MD, YA, MP, FBC. Literature search: AL, MD, YA, MP, FBC. Writing: AL, MD, YA, MP, FBC. Critical review: MD

REFERENCES

1. Beliveau PJH, Wong JJ, Sutton DA, et al. The chiropractic profession: a scoping review of utilization rates, reasons for seeking care, patient profiles, and care provided. *Chiropr Man Therap*. 2017;25:35.
2. Council on Chiropractic Internationale. The International Framework for Chiropractic Education and Accreditation. 2016. www.cceintl.org.
3. Triano JJ, Descarreaux M, Dugas C. Biomechanics–review of approaches for performance training in spinal manipulation. *J Electromyogr Kinesiol*. 2012; 22(5):732–739.
4. Descarreaux MC, Dugas C. Learning spinal manipulation skills: assessment of biomechanical parameters in a 5-year longitudinal study. *J Manipulative Physiol Ther*. 2010;33(3):226–230.
5. Rogers CM, Triano JJ. Biomechanical measure validation for spinal manipulation in clinical settings. *J Manipulative Physiol Ther*. 2003;26(9):539–548.
6. Downie AS, Vemulpad S, Bull PW. Quantifying the high-velocity, low-amplitude spinal manipulative thrust: a systematic review. *J Manipulative Physiol Ther*. 2010;33(7):542–553.
7. Schmidt RA, Lee TD. *Motor Control and Learning: A Behavioral Emphasis*. 5th ed. Champaign, IL: Human Kinetics; 2011.
8. Triano JJ, Gissler T, Forgie M, Milwid D. Maturation in rate of high-velocity, low-amplitude force development. *J Manipulative Physiol Ther*. 2011;34(3):173–180.
9. Junaid KA, Fellowes S. Gender differences in the attainment of motor skills on the Movement Assessment Battery for Children. *Phys Occup Ther Pediatr*. 2006;26(1-2):5–11.
10. Rohr LE. Gender-specific movement strategies using a computer-pointing task. *J Mot Behav*. 2006;38(6):431–437.
11. Starmer DJ, Guist BP, Tuff TR, Warren SC, Williams MG. Changes in manipulative peak force modulation

and time to peak thrust among first-year chiropractic students following a 12-week detraining period. *J Manipulative Physiol Ther*. 2016;39(4):311–317.

12. Advanced Mechanical Technology, I. OR6-7 Force platform characteristics. http://www.amti.uk.com/products/or6-7-force-platform.php. Published January 19, 2018.
13. Kimura D. *Sex and Cognition*. Cambridge: MIT Press; 2000: 230.
14. Descarreaux M, Dugas C, Raymond J, Normand MC. Kinetic analysis of expertise in spinal manipulative therapy using an instrumented manikin. *J Chiropr Med*. 2005;4(2):53–60.
15. Robert R. *Motricité humaine. Fondements et applications pédagogiques – Développement Moteur –Tome*, 2 ed. Québec: Presses de l'Université du Québec; 2012.
16. Gutnik B, Skurvydas A, Zuoza A, et al. Influence of spatial accuracy constraints on reaction time and maximum speed of performance of unilateral movements. *Percept Mot Skills*. 2015;120(2):519–533.
17. Johnson ST, Kipp K, Hoffman MA. Spinal motor control differences between the sexes. *Eur J Appl Physiol*. 2012;112(11):3859–3864.
18. Tun PA, Lachman ME. Age differences in reaction time and attention in a national telephone sample of adults: education, sex, and task complexity matter. *Dev Psychol*. 2008;44(5):1421–1429.
19. Fitts PM. Cognitive aspects of information processing. 3. Set for speed versus accuracy. *J Exp Psychol*. 1966; 71(6):849–857.
20. Rohr LE. Upper and lower limb reciprocal tapping: evidence for gender biases. *J Mot Behav*. 2006;38(1): 15–17.
21. van Abswoude F, Nuijen NB, van der Kamp J, Steenbergen B. Individual differences influencing immediate effects of internal and external focus instructions on children's motor performance. *Res Q Exerc Sport*;2018:1–10.