ORIGINAL ARTICLE

Correlation of expertise with error detection skills of force application during spinal manipulation learning*

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Objective: Most studies on spinal manipulation learning demonstrate the relevance of including motor learning strategies in chiropractic curricula. Two outcomes of practice are the production of movement in an efficient manner and the improved capability of learners to evaluate their own motor performance. The goals of this study were to evaluate if expertise is associated with increased spinal manipulation proficiency and if error detection skills of force application during a high-velocity low-amplitude spinal manipulation are related to expertise.
Methods: Three groups of students and 1 group of expert chiropractors completed 10 thoracic spine manipulations on an instrumented device with the specific goal of reaching a maximum peak force of 300 N after a brief period of practice. After each trial, participants were asked to give an estimate of their maximal peak force. Force-time profiles were analyzed to determine the biomechanical parameters of each participant and the participant's capacity to estimate his or her own performance.
Results: Significant between-group differences were found for each biomechanical parameter. No significant difference was found between groups for the error detection variables ($p > .05$). The lack of significant effects related to the error detection capabilities with expertise could be related to the specificity of the task and how the training process was structured.
Conclusion: This study confirms that improvements in biomechanical parameters of spinal manipulation are related to expertise. Feedback based on error detection could be implemented in chiropractic curricula to improve trainee abilities in detecting motor execution errors.

Key Indexing Terms: Spinal Manipulation; Learning; Chiropractic; Psychomotor Performance

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INTRODUCTION

Motor learning is of crucial importance in many health disciplines such as dentistry, chiropractic, and physical therapy.[1,2] Clinical training in manual therapies using high-velocity low-amplitude spinal manipulation (HVLA-SM) procedures, similar to other motor skills, is modulated by intrinsic (e.g., central nervous system maturation, physical capabilities) and extrinsic factors (practice schedule, knowledge of performance, and knowledge of results).[3] The rate of HVLA-SM skill development using various combinations of laboratory and instructional procedures has been measured, and several studies have identified parameters such as preload force, which is the gradual force applied to the spine before the thrust, time-to-peak force (impulse duration), peak force, and thrust rate as predictors of performance and expertise.[3–8] Most studies investigating HVLA-SM learning have used either human subjects or instrumented devices (manikins, force plates, strength gauges) and clearly demonstrated the relevance of including motor learning strategies as soon as possible in the chiropractic curriculum.[3,8–12]

It has been suggested that practice is a key element of motor skill acquisition and that the amount of practice can increase the strength of the recognition memory when paired with appropriate feedback (knowledge of results or knowledge of performance).[13] Recent studies have confirmed that extrinsic feedback from a teacher and visual or auditory information provided with an instrumented teaching device improves HVLA motor skills in novices.[3,11] Major outcomes of practice include the ability to

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produce movement in a more efficient manner[14] and the improved capability of learners to evaluate their own motor performance.[15]

Error Detection Capability

One's ability to evaluate his or her own performance can be evaluated through error detection capability. For instance, experts' performance is characterized by improved monitoring of sensory feedback that allows them to use performance-related information to perceive an error. Detecting an error requires an accurate perception of the speed, force, distance, or duration of the movement and the ability to compare the action to a predetermined reference.[16] Learning a specific motor task allows the development of a reference of correctness (memory trace) that is compared to the executed movement, allowing detection and correction of the movement in subsequent attempts.[17,18] In a study by Schmidt and White,[19] subjects were asked to move using a ballistic-timing task, a slide with a follow-through over a predetermined distance, with a target movement time of 150 milliseconds. Subjects were then asked to estimate their movement duration after each trial. To quantify the error detection capabilities of subjects, the estimates were subtracted from the real movement time (subjective error) and correlated to the real movement time subtracted from the target movement time (objective error). The hypothesis was that an increased correlation between the subjective and objective errors would reflect a better error detection mechanism. Results from the study indicated that the correlation increased from 0.28 to 0.76 over a session of 120 practice trials. One of the known benefits of practice is that learners, particularly when they achieve high levels of proficiency, will become less dependent on external feedback (instructors and instrumented feedback), concomitantly relying on improved error detection capability to assess their own performance.

To our knowledge, no previous study has been conducted on error detection capabilities of force application while performing HVLA-SM or HVLA simulations. Therefore, the goals of this study were to evaluate if expertise leads to a more efficient movement and if error detection skills in HVLA simulation force application improve with expertise. Based on previous studies,[3,8] it was hypothesized that biomechanical parameters of spinal manipulation would improve with the level of expertise and that the error detection skills are significantly better in experienced clinicians.

METHODS

Sixty-three participants involved in a chiropractic program favoring a mixed pedagogical strategy with positioning training and complete practice of HVLA-SM skills voluntarily participated in the current study. Given that there were no data available to conduct a standard sample size calculation, the sample size estimate was based on similar studies investigating expertise in spinal manipulation.[8,20,21] All participants gave their informed written consent according to the protocol approved by the Ethics Committee Research Involving Humans at Université du Québec à Trois-Rivières (CER-14-201-07.17). Participants were all tested during the same week during a brief (15–20 minutes) session conducted in the institution's research laboratory.

Four different groups of participants were tested based on their clinical experience and expertise. Group 1 (N = 15; mean age = 20.3) exclusively consisted of 1st-year students of the chiropractic program who had no previous experience with HVLA-SM or HVLA simulation and only theoretical notions related to positioning and HVLA-SM techniques. Group 2 (N = 17; mean age = 23) comprised 4th-year students, with 3 years of supervised clinical practice. Group 3 (N = 15; mean age = 24.2) included 5th-year students with 4 years of supervised clinical practice. Participants in group 4 (N = 16; mean age = 36.8) were all experienced chiropractors with clinical postgraduation experience ranging from 2 to 44 years of clinical practice. Participants' characteristics are presented in Table 1.

Participants were instructed to complete 10 consecutive trials of their best thoracic spine manipulations on an instrumented device using a right-handed pisiform contact. The maneuver, identified as a prone unilateral hypothenar transverse push adjustment, was performed with a posterior-to-anterior force vector (relative to the instrument) using either a left or right contact and the body positioning of their choice. All participants were instructed to perform the HVLA-simulated procedure using preload, and a demonstration trial was performed by the same author (JT) to properly illustrate and identify the procedure and the contact point. No feedback regarding their performance was provided for these first 10 trials. Participants were then asked to perform 15 practice trials of the same HVLA simulation technique with the specific goal of reaching a maximum peak force of 300 N. This value is inferior to those reported in the literature and was selected to ensure that 1st-year students could reach it.[4] This familiarization phase was conducted so that all subjects could gauge the level of resistance offered by the device and learn how to reach the target force. After each trial, participants were shown their force-time curve, and the maximum force reached was provided both verbally and visually. Finally, participants were asked to complete 10 additional trials and still try to reach 300 N without being provided with feedback. After each trial, participants were asked to give an estimate of the maximal peak force that was reached. All task requirements and all instructions provided to the participants were identical for all 4 groups of participants.

Spinal manipulations were performed on a computer-connected device developed to simulate a thoracic spine and to record obtained force-time profiles for HVLA simulation analysis. Participants placed their hands on a device contact point linked to a strain gauge (model UL 400, Statham Inc, Oxnard, CA) by a spring that allowed replicating movements and resistance of the thoracic spine. Applied vertical forces over the contact point were recorded with the strain gauge and displayed in real time on the computer screen. In order to simulate the articular

Table 1 - Participants' Characteristics

Group	No.	Men	Women	Mean Age, y (SD)	Weight, kg (SD)	Height, m (SD)	Years of Training	Years of Clinical Experience
1st year	15	5	10	20.3 ± 3.9	65.1 ± 10.8	1.71 ± 8.4	0	0
4th year	17	9	8	23.0 ± 1.5	66.2 ± 11.1	1.73 ± 10.5	3	0
5th year	15	9	6	24.2 ± 1.1	70.6 ± 16.9	1.71 ± 6.6	4	1
Experts	16	10	6	36.8 ± 11.34	72.6 ± 14.2	1.73 ± 9.1	–	2–44

release characterizing a vertebral joint cavitation, a moving piece (the contact point, the spring, and the strain gauge) was set to drop down 5 mm when a threshold force parameterized from the computer was reached during HVLA simulations (set to 300 N). The target force was set at 300 N so that all participants could easily reach this value regardless of their expertise or any mechanical and anthropometric disadvantages. Before performing spinal manipulation, an electromagnet (model EM300-24-212, APW Company, Rockaway, NJ) fixed to the device was activated by the computer to attract the lower component of the device and move it up in position. During the manipulation, a device circuit compared the strain gauge–measured force with the threshold force every millisecond. When the measured force exceeded the threshold force, the electromagnet was switched off and the lower portion of the device dropped down. An acquisition card (NI USB-6008, National Instruments, Austin, TX) connected by a USB cable between the device and the computer allowed data collection using Labview software (National Instruments, Austin, TX).

The force-time signals were analyzed to determine the onset of force, peak force applied, and preload force. All parameters were analyzed for each trial and each participant. The data were then used to calculate time-to-peak force (thrust duration) and rate of force application. Three measures of mean error for peak force were calculated: subjective error (SE), objective error (OE), and variable error (VE). For each experimental trial, peak force was measured as the highest force value reached in the force-time curve. Using this information, SE, OE, and VE in peak force were calculated and compared for each trial and each participant. SE measures the participants' ability to accurately estimate their peak force and represents the positive or negative difference between the actual and estimated peak forces. A positive SE corresponds to an underestimation of the force reached, and a negative SE corresponds to an overestimation of the force reached. The participants' ability to accurately reach the target force of 300 N was termed OE and represents the target force subtracted from the peak force reached. VE measures the inconsistency in peak force and represents the difference between the participants' peak force score on each trial and their own average score. Thus, if participants generated peak force very consistently, their VE tended to be small.

Peak force data (SE, OE, and VE) and the 4 basic biomechanical parameters were analyzed with 1-way analysis of variance (ANOVA) separately for each variable. Effect size was calculated using partial eta-squared values and the significance level was set at $p < .05$ for all analyses. The statistical analysis was performed using Statistica 10 (StatSoft, Inc, Tulsa, OK).

RESULTS

ANOVA assumptions (normal distribution of data and homogeneity of variances) were met, and the analyses yielded significant between-group differences for each of the 4 basic biomechanical parameters of HVLA simulations. A significant difference in preload forces (F [3, 561] = 35.18, $p < .0001$, $\eta p^2 = .15$) was observed between 1st-year students and the 3 other groups (4th and 5th year, experts). Time-to-peak force values significantly decreased (F [3, 561] = 28.14, $p < .0001$, $\eta p^2 = .13$) from 1st-year students to experts, with significant differences observed between each group except the 4th- and 5th-year students. The thrust force significantly increased (F [3, 561] = 17.33, $p < .0001$, $\eta p^2 = .09$) from the 1st- to the 5th-year students, with values similar to the experts observed in the 4th and 5th year. Finally, a rate of force application significantly increased with experience (F [3, 561] = 38.7, $p < .0001$, $\eta p^2 = .17$). Figure 1 illustrates the mean values for preload, time-to-peak force, peak force, and thrust rate for all 4 groups.

With regard to error-detecting capabilities, no significant between-group differences were found for any of the 3 variables of interest (for all, $p > .05$). Mean (SD) values for SE, OE, and VE are presented in Table 2.

DISCUSSION

The objectives of this study were twofold: firstly, to evaluate if biomechanical parameters of HVLA simulation improve with the level of expertise, and secondly, to assess if error detection capability during HVLA simulation force application improves with expertise. Overall, the results indicate that there is a significant improvement in all 4 basic biomechanical parameters from the 1st-year student group to the expert group. The large increase observed in preload force from the 1st- to the 4th-year participants could be explained by the fact that the 1st-year students had no formal practice of HVLA-SM and that this concept of preload force was unfamiliar to them. As shown in a previous study, preload forces are quite variable during the first 2 years of training, and definite patterns of improvement are difficult to identify.[8] Time-to-peak force decreased steadily with the level of expertise, whereas the peak force increased for all 3 groups of students, typically characterizing improvements in HVLA simulation skills

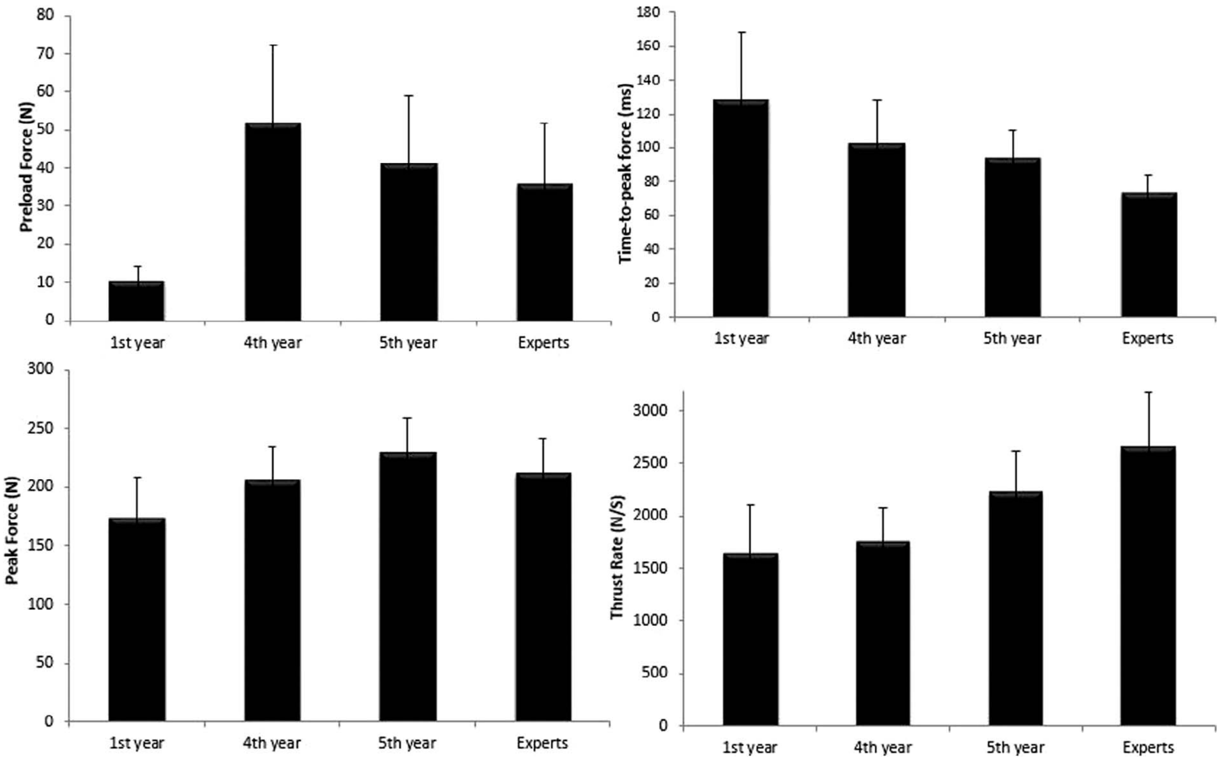

Figure 1 - Mean (SD) values of preload force, time-to-peak force, peak force, and rate of force application of 1st-year students, 4th-year students, 5th-year students, and experts.

throughout practice. Similar observations have been reported in previous studies confirming that HVLA simulation biomechanical parameters improve with clinical experience and that the participants involved in the present study represent typical chiropractic students and expert chiropractors.[3,8,12]

The present study failed to identify any between-group difference in the error detection capability variables. The lack of significant expertise effect in error detection capability could be related to the traditional teaching methods used in the training of HVLA-SM procedures. For instance, learning to detect and correct one's own error is an important skill in itself that requires practice. To the best of our knowledge, error detection is not an intricate component of HVLA-SM training, and students, although they learn to produce various force levels, are rarely provided with objective quantified feedback related to force application. Thus, one could argue that all the participants in this study were novices in the interpretation of sensory feedback related to errors. Consequently, regardless of their clinical expertise, experts and trainees were not familiar with such information and how this information could be used to generate appropriate corrections in the following HVLA simulation attempts. A study by Robertson et al.[22] comparing novice and skilled gymnasts walking across a balance beam as quickly as possible with and without vison of the beam identified clear differences between the 2 groups. Indeed, their results showed that experts, adequately correcting movement errors, were less affected by the elimination of vision than novice beam-walkers. One possible explanation for the lack of expertise effect in HVLA error detection is that, as opposed to novice and expert chiropractors, novice and expert gymnasts are trained to detect their movement errors and to implement corrections as they progress through years of training.

Limitations and Practical Implications

Given the usual organization of practice and learning sessions in HVLA-SM training, error detection capability may not currently be an adequate variable to assess expertise since error-detecting skills are not formally included in training. Providing augmented feedback to

Table 2 - Mean (SD) Values for All 3 Measures of Error (Subjective, Objective, and Variable Error) for Each Group

Group	Subjective Error	Objective Error	Variable Error
1st year	12.96 ± 18.09	61.45 ± 58.85	29.15 ± 17.14
4th year	20.21 ± 28.81	36.79 ± 41.30	30.03 ± 14.78
5th year	22.53 ± 31.04	26.13 ± 59.44	27.50 ± 8.55
Experts	6.88 ± 35.84	30.79 ± 67.36	31.87 ± 16.35

trainees has been shown to improve performance[3] and could be used to implement a learning procedure that emphasizes error detection and related movement corrections.

In order to assess the quality and the generalizability of the acquired processes, future research should investigate complementary indicators of expertise such as the transfer of learning of 1 specific task to variations of this task. Generalization or transfer of motor learning refers to individuals applying what has been learned in one context to another that shares similar characteristics.[23,24] Such a variable may be better suited in chiropractic training, since daily practice of HVLA-SM involves high levels of adaptation and contextualization of the task (table height, patient's morphology, clinical status).

CONCLUSION

This study demonstrates that clinical experience and level of training seem to be important factors leading to improvement in HVLA-SM and HVLA simulation skills. As for error detection capabilities, no significant difference was found between students and experts. Feedback based on error detection could be implemented in chiropractic programs to allow future clinicians to increase their skills at detecting errors and perhaps improve procedure safety.

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References

1. Elliott, D, Grierson LE, Hayes SJ, Lyons J. Action representations in perception, motor control and learning: implications for medical education. *Med Educ*. 2011;45(2):119–131.
2. Reznick RK, MacRae H. Teaching surgical skills–changes in the wind. *N Engl J Med*. 2006;355(25):2664–2669.
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. 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.
5. Nougarou F, Dugas C, Loranger M, Page I, Descarreaux M. The role of preload forces in spinal manipulation: experimental investigation of kinematic and electromyographic responses in healthy adults. *J Manipulative Physiol Ther*. 2014;37(5):287–293.
6. Page I, Nougarou F, Dugas C, Descarreaux M. The effect of spinal manipulation impulse duration on spine neuromechanical responses. *J Can Chiropr Assoc*. 2014;58(2):141–148.
7. Nougarou F, Dugas C, Deslauriers C, Page I, Descarreaux M. Physiological responses to spinal manipulation therapy: investigation of the relationship between electromyographic responses and peak force. *J Manipulative Physiol Ther*. 2013;36(9):557–563.
8. Descarreaux M, 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.
9. Harvey MP, Wynd S, Richardson L, Dugas C, Descarreaux M. Learning spinal manipulation: a comparison of two teaching models. *J Chiropr Educ*. 2011;25(2):125–131.

10. Triano JJ, Scaringe J, Bougie J, Rogers C. Effects of visual feedback on manipulation performance and patient ratings. *J Manipulative Physiol Ther*. 2006; 29(5):378–385.
11. Descarreaux M, Dugas C, Lalanne K, Vincelette M, Normand MC. Learning spinal manipulation: the importance of augmented feedback relating to various kinetic parameters. *Spine J*. 2006;6(2):138–145.
12. Enebo B, Sherwood D. Experience and practice organization in learning a simulated high-velocity low-amplitude task. *J Manipulative Physiol Ther*. 2005;28(1):33–43.
13. Schmidt RA. A schema theory of discrete motor skill learning. *Psychol Rev*. 1975;82:225–260.
14. Schmidt RA, Lee TD. *Motor Control and Learning: A Behavioral Emphasis*. 4th ed. Champaign, IL: Human Kinetics; 2005.
15. Adams JA. A closed-loop theory of motor learning. *J Mot Behav*. 1971;3:111–149.
16. Sherwood DE. Detecting and correcting errors in rapid aiming movements: effects of movement time, distance, and velocity. *Res Q Exerc Sport*. 2010;81(3):300–309.
17. Wulf G. *Attention and Motor Skill Learning*. 1st ed. Champaign, IL: Human Kinetics; 2007.
18. Schmidt R, Lee T. *Motor Control and Learning*. 4th ed. Champaign, IL: Human Kinetics; 2005.
19. Schmidt RA, White JL. Evidence for an error detection mechanism in motor skills. *J Mot Behav*. 1972;4(3): 143–153.
20. 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.
21. Descarreaux M, Dugas C, Treboz J, Cheron C, Nougarou F. Learning spinal manipulation: the effect of expertise on transfer capability. *J Manipulative Physiol Ther*. 2015;38(4):269–274.
22. Robertson S, Collins J, Elliott D, Starkes J. The influence of skill and intermittent vision on dynamic balance. *J Mot Behav*. 1994;26(4):333–339.
23. Criscimagna-Hemminger SE, Donchin O, Gazzaniga MS, Shadmehr R. Learned dynamics of reaching movements generalize from dominant to nondominant arm. *J Neurophysiol*. 2003;89(1):168–176.
24. Krakauer JW, Mazzoni P, Ghazizadeh A, Ravindran R, Shadmehr R. Generalization of motor learning depends on the history of prior action. *PLoS Biol*. 2006;4(10):e316.