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Effects of practice variability on spinal manipulation learning*

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Objective: To evaluate the effects of practice variability on chiropractic students' capacity to deliver spinal manipulations (SMs) of a targeted peak force.

Methods: Forty students participated in an experimental session including either a variable or a constant practice protocol of 45 SMs. SMs were delivered on a computer-connected device that recorded force-time profiles. Ten SMs with a target peak force of 350-N were performed before practice, immediately following practice, and 2 days later. Mixed-design analyses of variance were used to assess the effect of practice type on SM biomechanical parameters and on the constant, the absolute error (AE), and the variable error (VE).

Results: The practice period led to significantly more accurate ($F_{AE}[2,76] = 6.17$, $p < .01$) and consistent ($F_{VE}[2,76] = 3.90$, $p = .02$) performances at the postintervention assessment regardless of practice type. Among biomechanical parameters, preload force was higher at the retention assessment than at baseline ($F[2,76] = 6.53$, $p < .01$), while rate of force application significantly decreased between the baseline and the retention assessment ($F[2,76] = 4.10$, $p = .02$).

Conclusion: This experimental study showed that 1 session of SM practice including feedback leads to an increase in SM peak force accuracy and consistency, whether or not the practice period included variable practice. The current results confirmed that short practice periods with feedback should be included in the chiropractic curriculum.

Key Indexing Terms: Manipulation, Spinal; Motor Skills; Chiropractic; Learning

J Chiropr Educ 2017;31(2):90–95 DOI 10.7899/JCE-16-8

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INTRODUCTION

Chiropractic is one of the most sought-after complementary and alternative medicines; for back and neck pain, the 1-year prevalence of consultation in chiropractic in the United States is estimated between 20% and 74%.[1,2] Despite a wide range of therapeutic modalities being offered by chiropractors, spinal manipulation (SM) is perceived to be the foundation of the chiropractic technique and is the most commonly used therapy by these health professionals.[3,4] SM is defined as a specific form of joint manipulation using either long- or short-leverage techniques targeting specific anatomic contacts or structures, and it is characterized by a low-amplitude dynamic thrust of controlled velocity, amplitude, and direction.[5] Traditionally, SM skills are acquired mainly through a combination of observation of qualified instructors and formal practice with peers. Although observational practice can provide unique and important contributions to learning, learners benefit even more when it is combined with physical practice and integrated motor-learning programs.[6]

Chiropractic colleges recently began to include motor learning principles in their SM teaching curriculum.[7,8] Many of these principles have now been investigated in the context of SM learning, and relevant studies confirmed that SM learning follows these principles.[9] Indeed, it has been shown that SM skill acquisition is gradually acquired through the teaching curriculum,[10,11] that sequencing of theory and laboratory exercises is important,[12] that augmented feedback is valuable in SM skill development,[13–15] and that transfer capability assessments should be considered in SM training.[16] To our knowledge, benefits of task-induced variability during practice of accuracy and consistency have not been investigated in the context of SM learning.

According to motor-learning *schemas* theory,[17,18] variable practice offers valuable insights for learning skills of a wide range of inherent variability levels. These *schemas* consist in the development of relationships between a predefined goal and the parameters used to achieve this

*This paper was selected as a 2016 Association of Chiropractic Colleges - Research Agenda Conference Prize Winning Paper - Award funded by the National Board of Chiropractic Examiners.

goal (retention situation) or a similar one (transfer situation). Consequently, effects of task-induced variability at the goal level (eg, varying force or velocity targets) or the execution level (ie, ways to achieve a given goal) have been studied in several motor skills, including tennis drive,[19] unimanual arm rotation,[20] manual aiming,[21,22] hand force production,[23,24] volleyball serve,[25] and shoulder adduction.[26] Although not consistent,[24] task-induced variability at the goal level typically results in lower accuracy and consistency, as measured by the absolute,[19,22] constant error,[19] or the root-mean-square jerk[20] immediately after the learning period. Nevertheless, it increases both the accuracy and consistency during a retention task (ie, after a rest period), thus leading to enduring changes in a person's capacity to achieve a skill.

It has recently been suggested that proper modulation of peak force and other SM biomechanical parameters according to patients' characteristics could increase safety and effectiveness of SM interventions.[8] If such hypothesis holds true, and with the knowledge that peak force control evolves throughout clinical training,[10,11] increasing accuracy and consistency in the execution of SM for various force levels through variable practice might become one important goal of the SM skill-learning process.

Considering the above-mentioned evidence, the objective of the present study was to evaluate the effects of task-induced variability during SM practice on chiropractic students' capacity to accurately and consistently deliver SMs. It was hypothesized that, immediately following the practice period, the use of a variable practice would be deleterious compared with a constant practice. However, variable practice would result in better accuracy and consistency at retention (after a 2-day rest period).

METHODS

Participants

To be included in the study, volunteers had to be 4th- or 5th-year chiropractic students (ie, being at their 1st- or 2nd-year chiropractic internship), had to be available for 2 assessment sessions at 48-hours' interval, and could not have any actual or previous injury limiting their capacity to perform spinal manipulations using the unilateral hypothenar transverse push technique. Moreover, participants could not have the intent to perform an unusual number of spinal manipulations between sessions, for example, by participating in chiropractic technique practice groups. No volunteers were excluded based on these criteria, and, consequently, 40 participants were assigned to either the variable practice group or the constant practice group. Allocation was made based on a pairwise distribution so that the groups would remain comparable for height, weight and years of experience with SM. A sample size of 20 participants per group was estimated based on previous studies[15,16] evaluating motor learning principles in SM learning. Informed written consent was obtained from each participant according to the ethics certificate delivered by the ethics committee for human subjects at Université du Québec à Trois-Rivières (CER-15-213-07.15).

Experimental Procedure

During the first experimental session, each participant delivered a total of 75 SMs on an instrumented device using a unilateral hypothenar transverse push technique[5] with a posterior to anterior force vector. Participants were asked to choose their preferred table side and height to perform SMs in a fencer position using the caudal hand pisiform to touch the device contact point. A familiarization period, consisting of 10 trials in which participants were instructed to perform, as accurately as possible, SMs with a peak force of 350-N, was first conducted. Verbal feedback giving the peak force attained was provided to participants after each trial. For the following trials ($n =$ 10), which were used as the baseline assessment, participants also targeted 350-N peak force, but without receiving feedback. A practice period followed, during which the participants performed 45 SMs, each followed by verbal feedback with regard to the peak force reached. For the constant practice group, the target peak force was kept constant at 350 N, whereas it randomly varied between 300 N, 350 N, and 400 N for the variable practice group. Finally, as a postintervention assessment, another set of 10 trials targeting a 350-N peak force were performed without feedback.

Two days later, participants performed without feedback a retention set of 10 SMs with a 350-N target peak force. All 3 sets of 10 trials collected during the baseline and the postintervention and retention assessment periods were used in the data analysis. Moreover, at the beginning of this second assessment period, participants were asked the number of SMs they had executed since the first assessment.

Apparatus

SMs were delivered on a computer-connected device developed to emulate a thoracic spine prone manipulation while recording force-time profiles. A complete description of the apparatus has already been published.[16] The contact point on the device is linked to a strain gauge by a spring (model IL 400, Statham, Inc, Oxnard, CA) that replicates thoracic spine movement and resistance. To simulate a vertebral joint cavitation, the moving piece (consisting of the contact point, the spring, and the strain gauge) dropped off 5 mm when a force of 250 N was reached during SM. Data were collected using Labview software (National Instruments, Austin, TX).

Data Analysis

Force-time signals obtained during the 3 assessment blocks (baseline, postintervention, and retention) were analyzed to determine each trial preload force, onset of thrust, and peak force. Thrust duration and rate of force application were then calculated.

The constant error (CE), the absolute error (AE), and the variable error (VE) were calculated per participant for the 3 assessment blocks, with 350 N considered to be the target peak force. CE represents the positive or negative difference 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

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represents the participants' consistency and was defined as the absolute of the 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

T tests for independent samples were conducted to assess groups' similarities in participants' baseline characteristics (age, height, and weight) as well as to assess differences in the number of SMs performed between the 2 evaluation days. Error variables (CE, AE, and VE) and the 4 basic biomechanical parameters (peak force, preload force, thrust duration, and rate of force application) were independently subjected to a mixed-design analysis of variance with 2 group levels (constant and variable practice) and 3 time of measurement levels (baseline, postintervention, and retention). When required, post hoc analyses were performed using Tukey tests, and the 95% confidence intervals (CI) were calculated. All statistical analyses were computed with Statistica 10 (Statsoft, Tulsa, OK), and the level of significance was set to $p = .05$.

RESULTS

Participants

T tests for independent samples revealed that the constant ($n = 20$) and the variable ($n = 20$) practice groups were similar for age (mean ± SD = 23.80 ± 1.82 y; 23.9 ± 2.07 y, respectively), height (1.72 ± 0.10 m; 1.74 ± 0.10 m, respectively), weight (70.00 ± 13.08 kg; 72.12 ± 13.70 kg, respectively), and number of SMs performed between evaluation days (13.5 ± 11.48; 17.55 ± 13.46, respectively) ($p > .05$ for all). Both groups included 10 females and 16 5th-year students.

Effects of Practice Type on SM Performance

The analysis revealed an effect of time on AE ($F[2,76] = 6.17$, $p < .01$) and VE ($F[2,76] = 3.90$, $p = .02$). The Tukey test showed that both AE and VE were lower at the postintervention assessment than at baseline. No group effect was observed for CE ($F[1,38] = 0.00$, $p = .99$), AE ($F[1,38] = 0.36$, $p = .55$), or VE ($F[1,38] = 0.01$, $p = .93$), and no time effect was observed for CE ($F[2,76] = 0.87$, $p = .42$). Similarly, no group × time interaction was present for any of the dependent variables: $F_{CE}(2,76) = 0.20$, $p = .82$; $F_{AE}(2,76) = 0.77$, $p = .47$; and $F_{VE}(2,76) = 0.94$, $p = .39$. Overall, these results revealed that regardless of the practice type, the practice period led to significantly more accurate and consistent performances at the postintervention assessment. Mean (± SE) error values through time for both groups are presented in Figure 1.

SM Biomechanical Parameters

A time effect was observed for preload force ($F[2,76] = 6.53$, $p < .01$) and rate of force application ($F[2,76] = 4.10$, $p = .02$). The Tukey test revealed that preload force was higher at the retention assessment than at baseline, and that rate of force application decreased between baseline and retention assessment. No time effect was observed for thrust duration ($F[2,76] = 0.46$, $p = .65$) or peak force ($F[2,76] = 0.87$, $p = .42$). Similarly, no group effect or group × time interaction was observed for any of the biomechanical parameters (*F* values for the group effect are listed first in each of the following): peak force ($F[1,38] = 0.00$, $p = .99$ and $F[2,76] = 0.20$, $p = .82$), preload force ($F[1,38] = 0.83$, $p = .37$ and $F[2,76] = 0.67$, $p = .52$), thrust duration ($F[1,38] = 0.24$, $p = .63$ and $F[2,76] = 0.28$, $p = .76$), and rate of force application ($F[1,38] = 0.92$ $p = .34$ and $F[2,76] = 1.84$ $p = .17$). The means (SE) of SM biomechanical parameters with a 95% CI for the 3 assessments are presented in Table 1.

DISCUSSION

The purpose of the present study was to evaluate the effects of task-induced variability at the goal level on chiropractic students' capacity to accurately and consistently deliver SMs. It was initially hypothesized that, immediately following the practice period, the use of a variable practice would be deleterious compared with a constant practice, but that variable practice would result in better accuracy and consistency at retention. The results showed, however, that the improvement in motor performance was independent from the practice type. Both groups showed a decrease in absolute and variable errors between the baseline and postintervention assessments. The results obtained herein are in accordance with the most recent work by Triano et al.[27] in 2015, which showed that a 2-hour SM force modulation training in a group of experienced chiropractors (16.2 ± 9.8 years in practice) led to a 45% reduction in half-typical (200 N) force production and a 23% reduction in the double-typical (800 N) force production. It is well recognized that the amount of practice is one of the most important variables in motor learning, while other practice organization features, such as practice variability, practice distribution, and motivation, should be considered elements of optimization during practice sessions.[28] Based on the current results, short periods of practice including fewer than 50 SM trials are sufficient to improve accuracy and consistency in reaching a targeted peak force SM, irrespective of the practice type (ie, variable or constant).

Although the present study is the first to evaluate task-induced variability in SM training, results may be compared with the study by James and Conaster,[20] which evaluated the effect of practice variability on a simple unimanual arm rotation task. Their results showed that the low-variability group performed better (lower radioulnar and shoulder jerk) on the posttest, while the high-variability group performed better on the retention test. The training consisted of 20 practice trials performed twice a week for 2 weeks followed by a retention test 2 weeks after the end of the training. The procedure used in the present study included a lower number of practice trials (45 vs 80) performed over a shorter period of time in order to minimize the difference in the number of SMs performed outside the experiment by participants. Differences between constant practice and variable practice could perhaps be observed after longer practice periods and/or with a longer interval between the posttest and the

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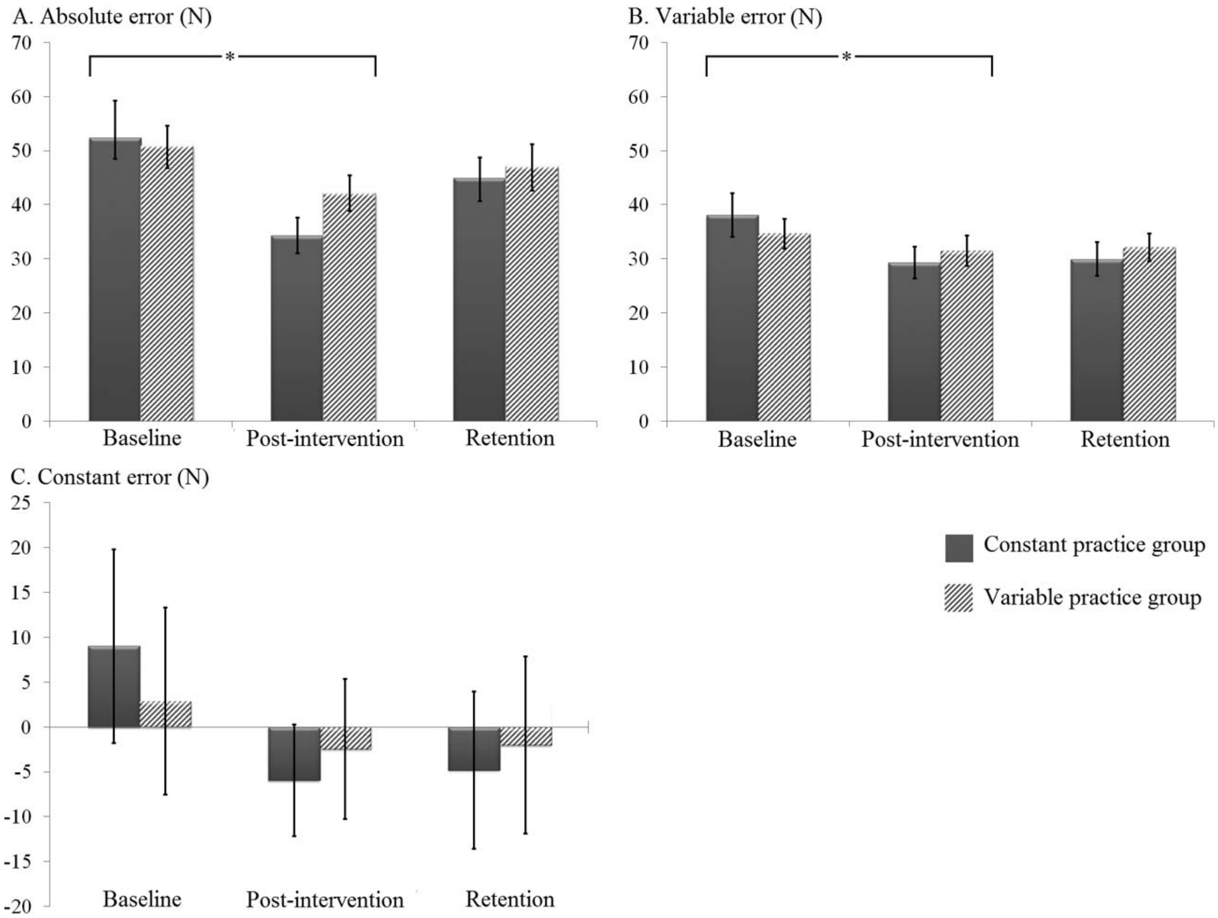

Figure 1 - Mean (SE) of the (A) absolute, (B) variable, and (C) constant errors for both groups during the 3 assessments. *Regardless of group, mean value was significantly higher at baseline than at the postintervention assessment ($p < .05$).

retention test. Furthermore, the present study only evaluated the effects of task-induced variability at the goal level on participants' capacity to achieve a preselected goal after a practice period, based on the fact that previous studies reported a deleterious effect of task-induced variability when the transfer situation[25,26] or execution level[23] was evaluated. Nevertheless, effects of task-induced variability at the execution level (variable ways to perform

Table 1 - Mean (SE) and 95% Confidence Interval (CI) of the 4 Spinal Manipulation (SM) Biomechanical Parameters During the 3 Assessments for the Constant and Variable Practice Groups.

		Constant Practice Group		Variable Practice Group	
Variable	Assessment	Mean (SE)	95% CI	Mean (SE)	95% CI
Peak force (N)	Baseline	358.99 (10.79)	336.40–381.58	352.87 (10.41)	331.09–374.66
	Postintervention	344.06 (6.23)	331.02–357.10	347.55 (7.81)	331.20–363.90
	Retention	345.19 (8.73)	326.92–363.47	347.98 (9.85)	327.37–368.59
Preload force (N)[a]	Baseline	114.72 (10.37)	93.01–136.42	108.16 (10.49)	86.22–130.11
	Postintervention	129.86 (10.22)	108.47–151.25	114.62 (11.28)	91.01–138.23
	Retention	137.37 (10.60)	115.19–159.55	120.30 (11.72)	95.77–144.83
Rate of force application (N/s)[b]	Baseline	4152.70 (262.80)	3602.66–4702.75	4182.04 (291.98)	3570.92–4793.17
	Postintervention	3460.70 (202.05)	3037.80–3830.60	4114.83 (344.15)	3394.52–4835.15
	Retention	3578.63 (272.57)	3008.13–4149.13	3907.88 (296.54)	3287.22–4528.53
Thrust duration (s)	Baseline	0.073 (0.003)	0.067–0.080	0.073 (0.005)	0.062–0.084
	Post-intervention	0.078 (0.005)	0.067–0.088	0.073 (0.006)	0.062–0.085
	Retention	0.076 (0.005)	0.065–0.086	0.072 (0.004)	0.063–0.080

[a] Regardless of group, preload was significantly higher during the retention assessment than the baseline assessment ($p < .01$).
[b] Regardless of group, rate of force application decreased significantly from the baseline to the retention assessment ($p = .02$).

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SM) or in a transfer task condition (eg, a different or variable peak force) can also be relevant in SM training.[16] Indeed, SM can be delivered through various techniques,[5] and clinicians should adapt their SM peak force depending on patients' characteristics and treatment goal.[8] Studies are thus needed to confirm whether variable practice is more effective than constant practice in SM training.

Interestingly, in this study, following the training periods, both groups of participants showed a decrease in their rates of force application as a result of increased preload force. Although studies on the evolution of SM biomechanical parameters have revealed that the rate of force application increases throughout the stages of training,[10,11] participants, when instructed to focus on thrust peak force, chose to modify their motor strategies by increasing preload forces. Shifts in motor strategies are commonly used and beneficial when searching for solutions that are more likely to succeed (ie, reach the target SM force).[28,29] In this particular case, participants may have increased preload forces and temporarily reduced rate of force application in order to increase their thrust peak force accuracy. One can suspect that further practice would have yielded improvement in the rate of force application (increase) once accuracy performance stabilized.

Strengths and Limitations

A total of 40 students were included in this study, which represents half of the interns available for recruitment. The sample used is believed to be a fair representation of 4th- and 5th-year chiropractic students' SM abilities. On the other hand, if participants had been at the beginning of their chiropractic training, with a more limited knowledge of SM biomechanical parameters, results favoring the variability practice group may have been achieved. The role of practice variability in early stages of SM motor learning remains to be explored. All students were evaluated over a 1-month period, and all retention assessments were conducted 2 days after the initial assessment, so the rapidly increasing number of SMs performed by students throughout their clinical internship is not believed to have influenced the results. Some participants reported sustained postexperiment pisiform pain or discomfort upon arrival on the second day of testing. This mild adverse event may have led to modifications in SM execution during the retention trials and could partly explain the lack of differences observed between groups at the retention assessment. The time interval between sessions was relatively short; future studies should include a long-term retention assessment in addition to a short-term one. Furthermore, the apparatus used does not have the same features as a human body, and the feedback usually offered by body structures was not available in this particular situation. As such, the results obtained in the present study may not be perfectly representative of SM practice on human bodies.

CONCLUSION

This experimental study showed that 1 session of SM practice that included feedback led to an increase in accuracy and consistency in achieving a targeted peak force in chiropractic students. This improvement was reached regardless of whether the practice period included practice of SM with a constant target peak force or a variable target peak force. Although studies are needed to assess the effects of task-induced variability at the execution level on SM learning and practice variability effects on transfer capability, the current results confirm that short practice periods with feedback should be included in chiropractic curricula.

FUNDING AND CONFLICTS OF INTEREST

This work was funded internally. The authors have no conflicts of interest to declare relevant to this work.

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Author Contributions

Concept development: IP, MD, CD. Design: AAM, MD, CD, IP. Supervision: AAM, MD, CD, IP. Data collection/processing: AAM, LM, IP. Analysis/interpretation: AAM, MD. Literature search: IP, LM. Writing: AAM, LM, CD, MD, IP. Critical review: AAM, LM, CD, MD, IP.

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References

1. Wolsko PM, Eisenberg DM, Davis RB, Kessler R, Phillips RS. Patterns and perceptions of care for

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treatment of back and neck pain: results of a national survey. *Spine (Phila Pa 1976)*. 2003;28(3):292–297; discussion 8.
2. Kanodia AK, Legedza AT, Davis RB, Eisenberg DM, Phillips RS. Perceived benefit of complementary and alternative medicine (CAM) for back pain: a national survey. *J Am Board Fam Med*. 2010;23(3):354–362.
3. French SD, Charity MJ, Forsdike K, et al. Chiropractic Observation and Analysis Study (COAST): providing an understanding of current chiropractic practice. *Med J Aust*. 2013;199(10):687–691.
4. Clijsters M, Fronzoni F, Jenkins H. Chiropractic treatment approaches for spinal musculoskeletal conditions: a cross-sectional survey. *Chiropr Man Therap*. 2014;22(1):33.
5. Peterson DH, Bergmann TF, Bergmann TF. Chiropractic Technique: Principles and Procedures. 2nd ed. St. Louis, MO: Mosby; 2002.
6. Wulf G, Shea C, Lewthwaite R. Motor skill learning and performance: a review of influential factors. *Med Educ*. 2010;44(1):75–84.
7. 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.
8. Triano JJ, Descarreaux M, Dugas C. Biomechanics—review of approaches for performance training in spinal manipulation. *J Electromyogr Kinesiol*. 2012; 22(5):732–739.
9. Stainsby BE, Clarke MC, Egonia JR. Learning spinal manipulation: a best-evidence synthesis of teaching methods. *J Chiropr Educ*. 2016;30:138–151.
10. 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.
11. 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.
12. Triano JJ, McGregor M, Dinulos M, Tran S. Staging the use of teaching aids in the development of manipulation skill. *Man Ther*. 2014;19(3):184–189.
13. Cuesta-Vargas AI, Williams J. Inertial sensor real-time feedback enhances the learning of cervical spine manipulation: a prospective study. *BMC Med Educ*. 2014;14:120.
14. Triano JJ, Rogers CM, Combs S, Potts D, Sorrels K. Quantitative feedback versus standard training for cervical and thoracic manipulation. *J Manipulative Physiol Ther*. 2003;26(3):131–138.
15. 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.
16. 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.
17. Schmidt R. A schema theory of discrete motor skill learning. *Psychological Review*. 1975;82(4):225–260.
18. Schmidt RA, Lee TD. *Motor Control and Learning: A Behavioral Emphasis*. 4th ed. Champaign, IL: Human Kinetics; 2005.
19. Douvis SJ. Variable practice in learning the forehand drive in tennis. *Percept Mot Skills*. 2005;101(2):531–545.
20. James EG, Conatser P. Effects of practice variability on unimanual arm rotation. *J Mot Behav*. 2014;46(4): 203–210.
21. Tremblay L, Welsh TN, Elliott D. Specificity versus variability: effects of practice conditions on the use of afferent information for manual aiming. *Motor Control*. 2001;5(4):347–360.
22. Ranganathan R, Newell KM. Motor learning through induced variability at the task goal and execution redundancy levels. *J Mot Behav*. 2010;42(5):307–316.
23. King AC, Newell KM. The learning of isometric force time scales is differentially influenced by constant and variable practice. *Exp Brain Res*. 2013;227(2):149–159.
24. Pease DG, Rupnow AA. Effects of varying force production in practice schedules of children learning a discrete motor task. *Percept Mot Skills*. 1983;57(1): 275–282.
25. Travlos AK. Specificity and variability of practice, and contextual interference in acquisition and transfer of an underhand volleyball serve. *Percept Mot Skills*. 2010; 110(1):298–312.
26. Newell KM, Shapiro DC. Variability of practice and transfer of training. *J Mot Behav*. 1976;8(3):233–243.
27. Triano JJ, Giuliano D, Kanga I, et al. Consistency and malleability of manipulation performance in experienced clinicians: a pre-post experimental design. *J Manipulative Physiol Ther*. 2015;38(6):407–415.
28. Schmidt RA. *Motor Control and Learning: A Behavioral Emphasis*. Champaign, IL: Human Kinetics; 1982.
29. Todorov E. Optimality principles in sensorimotor control. *Nat Neurosci*. 2004;7(9):907–915.

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