The effect of real-time feedback on learning lumbar spine joint mobilization by entry-level doctor of physical therapy students: a randomized, controlled, crossover trial

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ABSTRACT

Objective: To examine the effects of real-time, objective feedback on learning lumbar spine joint mobilization techniques by entry-level Doctor of Physical Therapy (DPT) students.

Methods: A randomized, controlled, crossover design was used. Twenty-four 1st Year DPT students were randomized into two groups. Group 1 ($n = 12$) practiced with the real-time feedback device first and then without it, while Group 2 ($n = 12$) practiced without the device first and then with it. Both practice periods with and without the device were 4 weeks long. Data were collected at Baseline, 5 weeks, 11 weeks, and 16 weeks. The crossover period was 5 weeks long, during which neither group practiced with or without the device. Eight force parameters were measured: R1 force; R2 force; Grade III and Grade IV mean peak force, frequency, and amplitude.

Results: When students practiced with the real-time feedback device, they more closely matched the reference standard for two outcomes: 1) the mean difference in R2 force between student and reference standard was better with device (38.0 ± 26.7 N) than without it (51.0 ± 38.5 N); $P = .013$; and 2) the mean difference in Grade III peak to peak amplitude force was also better with device (8.9 ± 9.3 N) than without it (11.8 ± 11.0); $P = .026$. All other force parameters improved when students practiced with the real-time feedback device, however, the differences between when they practiced without the device were not statistically significant.

Discussion: Real-time, objective feedback using a direct force measurement device improved learning for some aspects of lumbar spine joint mobilization by entry-level physical therapy students.

Level of Evidence: 2b

KEYWORDS

Manual therapy; motor skills; force

Introduction

Joint mobilization and manipulation are skilled passive movements used to evaluate and treat joint and soft tissue impairments [1,2]. These manual therapy movements vary in force, amplitude, and direction based on the desired outcome for treatment. One of the most common manual therapy techniques studied and used to treat lumbar spine pain is the central posterior-to-anterior (PA) mobilization [3–12]. Force parameters of this common evaluation and treatment technique are the first onset of resistance to joint movement or R1, the end of the joint resistance movement or R2, the mean peak force (MPF), force amplitude, and oscillation frequency. Mean peak force is the average of a series of force peaks; force amplitude is the difference between the peak and trough forces; and oscillation frequency is the number of force peaks per second or the rate of mobilization [9,12]. Maitland [13] and Grieve [14] have described various grades of mobilization based on the amount of resistance and magnitude of

movement. Grades I and II are designated as movements before R1 and are primarily used for pain modulation. Grades III and IV are for movements into resistance between R1 and R2 and are used primarily to increase joint motion respecting pain. Grades I and IV are performed using small amplitude movements, whereas Grades II and III utilize large amplitude movements. Maitland further refined the grades of mobilization using pluses and minuses. Minuses are used to indicate forces less than 50% of R1–R2 (e.g. Grade III- or IV- would represent 25% of the resistance range) and pluses are used to indicate forces above 50% of R1–R2 (e.g. Grade III+ or IV+ would represent 75% of the resistance range). When no plus or minus is used (e.g. Grade III or IV), it indicates 50% of R1–R2 [15–17].

Spinal and extremity joint mobilization and manipulation are common skills taught in entry-level physical therapy education [18–24]. Prior to graduation, physical therapy students must demonstrate an understanding of the indications and contraindications of manual therapy and demonstrate competence in these skills to

ensure they can be effectively and safely applied [2,23–28]. Traditionally, physical therapy students learn joint mobilization skills through observation of and interaction with an expert instructor followed by extensive practice of techniques on peers, faculty, and eventually patients [21,29]. This method may be less than ideal as there is little objective feedback about the forces applied. Perception of forces and subsequent verbal feedback about applied mobilization forces may be less accurate when compared to real-time quantified force measurements [29–32].

Previous studies have shown that student physical therapists demonstrate a high degree of variability when applying manual therapy forces as compared with experienced therapists [33–39]. However, research has also demonstrated that students can learn to be more consistent and accurate in applying manual forces when they receive more objective feedback [9,40–44]. One of the challenges in comparing studies on PA mobilizations is the inconsistency in the manual force application [12,45]. Different measurement devices have been utilized to measure spinal mobilization and manipulation forces including pressure devices [5,46–48], instrumented manikins [49–51], force plates positioned under the therapist [30,52–54], instrumented treatment tables [9,33,35,55–60], and tables positioned over force plates [34,41,61]. The majority of these measurement instruments record mobilization forces more indirectly, since the device is not between the therapist's hands and the actual joint being mobilized. However, flexible capacitance devices have been developed that provide more direct force measurement and have been used to measure cervical [48,62,63] and knee [64,65] joint mobilization forces.

To our knowledge, no study has investigated the use of these direct force measurement devices on the lumbar spine. Therefore, the aim of this study was to investigate the effects of real-time, objective feedback using a direct force measurement device on entry-level students learning multiple grades and forces of lumbar spine mobilization. By leveraging technology to provide precise feedback during manual skill practice, student physical therapists may be able to more quickly replicate the precision of expert joint mobilization forces utilized in published manual physical therapy clinical trials. The hypothesis was that practicing with the real-time feedback device would result in students more closely matching an expert's forces when performing the central PA lumbar spine mobilization technique.

Methods

Study design

A randomized, controlled, crossover design was used, with the participants acting as their own control by

undergoing both conditions of practicing with and without the real-time, objective feedback device. This design was efficient and practical as a smaller number of participants were required, and the study could be completed within an academic year. A random-number generator was used by the primary researchers to create the randomized list of participants in each group. Following randomization, group allocation was placed in opaque, sealed envelopes prior to enrollment. Participants in both groups were tested on 8 force parameters of the central PA lumbar spine mobilization technique: R1 force, R2 force, Grade III and Grade IV MPF, amplitude, and frequency. For this study, the Grade III and Grade IV MPF were defined as 50% between R1 and R2. All participants were tested on all force parameters at Baseline, 5 weeks, 11 weeks, and 16 weeks. The crossover period occurred after week 5 and lasted for 5 weeks. Student performance for each force variable was used to compare groups and was defined as the difference between the force parameter applied by a student and that applied by an expert physical therapist (PT). Each force parameter was analyzed separately. Additionally, students completed a demographic survey, which also included questions regarding their experience with and perceptions of using technology and receiving feedback to improve their learning.

Participants

Subjects

First-year students in an entry level Doctor of Physical Therapy (DPT) program were recruited as 'subjects' via electronic and in-class announcements at the University of the Incarnate Word (UIW) School of Physical Therapy in San Antonio, Texas, USA. Recruitment occurred between August and October 2018. All testing and practice periods were conducted from October 2018 through March 2019. All subjects were in their first semester of the program and had completed the module on the lumbar spine, which included instruction on lumbar spine manual therapy intervention. Manual therapy instruction was based on the Maitland concept and was received through a problem-based learning curriculum, which included expert demonstration, hands-on practice with peers, and verbal and tactile feedback from instructors. Subjects in the study were considered novice learners as they had not received any prior formal training or instruction in manual therapy. Subjects were excluded from the study if they had any of the following characteristics: 1) younger than 18 years of age, 2) not enrolled in an entry-level, accredited DPT program, 3) had current upper or lower extremity pain or disability which would cause them to not be able to perform joint mobilization techniques to the lumbar spine, or 4) unable to comply with the practice and testing schedule outlined in the study.

Mock patients

Mock patients for the study were recruited from the faculty, staff, and first- and second-year DPT students at UIW via the same method as the subjects. They were excluded if they had any of the following characteristics: 1) younger than 18 years of age, 2) any current low back or leg pain, 3) any previous history of back surgery, 4) any presence of spinal deformity, such as scoliosis, or 5) unable to comply with the practice and testing schedule outlined in the study.

Reference standard

A board-certified, fellowship trained manual physical therapist with 20 years of experience served as the reference standard for all comparison measurements. Previous studies on learning and assessing spinal joint mobilization and manipulation [9,12,30,41,53,60,66–68] have used expert practitioners as the reference standard as there is no current evidence on what ideal forces would be for effective mobilizations. In this study, the expert PT was tested for measurement accuracy by comparing the mean R1 to R2 force with the Grade III mean peak force. In theory, these forces should be the same, as Grade III mean peak force equals 50% of the force between R1 and R2. The expert PT was blinded to all force measurements and was found to be 92.3% accurate (mean % error $\pm$ SD, 7.7 ± 5.5) for all mock patients across all testing periods. The Institutional Review Board of the University of the Incarnate Word, San Antonio, Texas, USA approved this study and all participants gave informed consent, and their privacy and rights were protected.

Equipment

A small (10.5 $\times$ 5 cm), thin, loadpad force monitoring device (Novel Electronics Inc., St. Paul, MN) was used to record all force production data. (See Figure 1) The device is portable, light-weight, flexible, and highly compliant, which provides minimal disturbance to the proprioception of the practitioner. It is capable of

Figure 1. Loadpad force monitoring device.

accurately recording force magnitude, frequency, amplitude, timing, and rate of force production [64,65]. Data can be transmitted in real-time via Bluetooth and displayed to an iPad/iPhone screen. The display screen provides force-over-time visual and auditory feedback to the user. The loadpad was calibrated by the manufacturer prior to all data collection. Standard hi-lo examination tables were used to position the mock patients for the central PA lumbar mobilization. Metal music stands were used to hold the iPad devices while the subjects were practicing and testing with the device. (See Figure 2(a,b))

Feedback

Real-time feedback provided by the loadpad device consisted of visual representation of forces displayed on and auditory signals coming from the iPad. These two methods of feedback informed the subjects when their applied forces fell outside the prescribed ranges for each individual mock patient. All reference standard force parameters were set by the expert PT prior to each practice period. During the practice sessions with the device, subjects received visual and auditory concurrent feedback while applying the mobilization forces. Lines on the display screen marked the target force values for R1, R2, Grade III and Grade IV mobilization forces. When the subjects' forces were not within the value range set by the expert PT, a corresponding lower pitch sound beeped when they were too low; and a higher pitched sound beeped when they were too high for each force variable (negative feedback). When the subjects were within the prescribed values, no sound was produced. In addition to concurrent feedback, the subjects also received visual terminal feedback after each practice session as the device would capture all trials and display them as a whole. Each session was 15 minutes in length and consisted of practicing R1 for 2.5 minutes, R2 for 2.5 minutes, Grade III for 5 minutes, and Grade IV for 5 minutes. R1 and R2 forces were held for 5 seconds and then released, followed by a 10 second break. Grades III and IV mobilization were done for 30 second bouts with a 30 second rest period between bouts. This practice time was chosen to simulate what students might do in an actual educational program for one treatment technique like the central PA mobilization. Throughout the study, all subjects practiced in a room individually to prevent them from being distracted by other subjects and to blind them from the results of other subjects. Study personnel facilitated the practice sessions by setting the reference parameters on the iPad and keeping the subjects to the allotted practice times for each variable.

Procedures and data collection

A flow diagram of participant recruitment, allocation, and retention is in Figure 3. Following baseline testing

Figure 2. (a) Equipment setup for practice during study. (b) Close up of hand position.

Figure 3. Flow diagram of participant recruitment and retention.

for all subjects, Group 1 practiced the force parameters using the real-time feedback device once a week for 4 weeks. Group 2 simultaneously practiced for the same length and duration of time as Group 1, with the only exception being they practiced without the feedback device. All subjects were required to record their practice time in a log that was verified at each session by the study personnel. Subjects were retested at the 5-week mark for all 8 force parameters. The crossover occurred at the 5-week mark and included

a washout period of 5 weeks. During this time, all subjects did not practice the central PA technique with or without the device. This lengthy time period was chosen to minimize the carry-over learning effect from the previous practice. Following the washout period, both groups were again tested at the 11-week mark. Group 1 then began practicing without the device, while Group 2 began practicing with the device. The practice periods again lasted 4 weeks, with each weekly session lasting 15 minutes in

duration. The total practice time each subject recorded was 1 hour with the device and 1 hour without the device over the length of the study period. Following the final practice period, subjects were again tested on the 8 force parameters. Both the subjects and expert PT were blinded to the results during all testing periods. Study personnel collected the results of all 8 force parameters displayed on the iPad screen. (See Figure 4)

Practice and testing for all central PA mobilization force parameters were done on the L3 vertebra of each matched mock patient. The spinous process of L3 was marked by the expert PT each time with a small, removeable adhesive dot. This spinal level was chosen due to the orientation of the L3 vertebra being such that direct vertical forces can be applied [9]. The loadpad device was centered over the adhesive dot, directly on the mock patient's skin. All force parameters were performed using the pisiform handgrip, in which the proximal hypothenar eminence of one hand is placed on the spinous process of the vertebra and the opposite hand is placed over the top of the mobilizing hand for support [12]. (See Figure 2(b)) The expert PT provided the reference force parameters on each mock patient prior to each practice and testing session.

Data analysis

An a priori power analysis was performed using G*Power software 3.9.1.2 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). Using an alpha level

of 0.05 and an effect size of 0.25, we calculated the required sample size to be 24 subjects to have 80% power for the study. Data management and statistical analyses were performed using SPSS Version 25.0 (SPSS Inc, Chicago, IL). We analyzed each force parameter using a $2 \times 2 \times 2$ repeated-measures analysis of variance. The independent variables were Time (pre- and post-practice), Device (with and without), and Group Sequence (Group 1: with device first, then without it; and Group 2: without device first, then with it). The dependent variable was student performance measured by the absolute value of the difference between the student and expert physical therapist. Each parameter (R1 force [N]; R2 force [N]; Grade III and Grade IV MPF [N], peak to peak amplitude force [N], and oscillation frequency [Hz]) was analyzed separately.

Results

Twenty-four subjects with their matched mock patients participated in the study. Individual characteristics for both subjects and mock patients are presented in Table 1. One subject in Group 1 withdrew from the DPT program halfway through the study, so data for that subject were not included in the final analysis. No mock patients reported any harm or unintended effects as a result of participation in the study. Although the main and interaction effects were calculated for all independent variables, the one of greatest interest that answered the study's hypothesis was the interaction effect between Time (pre- and post-practice) and

Figure 4. Loadpad output screen on iPad.

Table 1. Individual characteristics of subjects and matched mock patients.

Characteristic	Subjects*		Mock Patients*	
	Group 1	Group 2	Group 1	Group 2
Age, years	24 ± 1.6	26 ± 5.2	27 ± 6.5	25 ± 4.7
Gender, n				
Female	7	8	4	4
Male	5	4	8	8
Height, m	1.73 ± 0.10	1.69 ± 0.08	1.71 ± 0.89	1.72 ± 0.11
Weight, kg	76.9 ± 14.0	71.1 ± 11.8	73.6 ± 13.5	71.8 ± 12.5
BMI, kg/m ²	25.7 ± 3.3	24.8 ± 3.0	24.9 ± 3.3	24.4 ± 3.0
Hand Dominance, n				
Right	10	10	n/a	n/a
Left	2	2		
Learning Style, n				
Auditory only	0	0	n/a	n/a
Visual only	0	0		
Hands-on	7	5		
Combination	5	7		
Confidence level using technology to enhance learning, 0–10 (0 = None; 10 = Highly)	8.0 ± 1.0	7.2 ± 2.3	n/a	n/a
Will Real-Time Feedback help me learn and retain manual skills?				
Yes	11	11	n/a	n/a
No	0	0		
Unsure	1	1		

Abbreviations: n, number; m, meters; kg, kilograms; BMI, body mass index; n/a, not applicable

*Values are mean ± SD unless otherwise indicated

Device (with and without). Subject performance for this interaction effect for all force parameters measured is found in Table 2. When the subjects practiced with the real-time feedback device, they more closely matched the expert for two outcomes: 1) the mean difference in R2 force between subject and expert was better with the device (38.0 ± 26.7 N) than without it (51.0 ± 38.5 N); $P = .013$; and 2) the mean difference in Grade III peak to peak amplitude force was also better with the device (8.9 ± 9.3 N) than without it (11.8 ± 11.0); $P = .026$. (See Figures 5–6) All other force parameters improved when subjects practiced with the real-time feedback device, however, the differences between when they practiced without the device were not statistically significant.

Discussion

This study investigated the effect of real-time, objective feedback using a direct force measurement device on entry-level students learning multiple grades and forces of lumbar spine mobilization. The findings demonstrate that this type of augmented feedback using a direct

measurement device was beneficial in helping students perform more closely to a fellowship-trained physical therapist on some lumbar spine mobilization parameters. Although all force parameters improved when students practiced with the real-time feedback device, only 2 of the 8 parameters measured showed a significant difference compared with when students practiced without the device. This indicates that practice alone, irrespective of the feedback device, was also beneficial to the students' performance. In this study, we tried to control for the learning effect by including a significantly long washout period (5 weeks) when students did not practice with or without the device. Despite this, we noted that some students were able to retain important information about manual force production and application despite the lack of practice.

Manual therapy and feedback

To our knowledge, this study represents the first to explore learning spinal joint mobilization skills for students in their first year of physical therapy school,

Table 2. Subject performance pre- and post-practice with and without the real-time feedback device.

Lumbar Spine Central PA Mobilization Parameters	WITH Device*		WITHOUT Device*		P Value†	Effect Size†	Power‡
	Pre-Practice	Post-Practice	Pre-Practice	Post-Practice			
R1 Force, N	31.6 ± 34.1	22.5 ± 18.1	29.2 ± 25.5	36.0 ± 25.2	.077	.141	.427
R2 Force, N	62.6 ± 37.5	38.0 ± 26.7	47.2 ± 40.4	51.0 ± 38.5	.013‡	.262	.740
Grade III MPF, N	49.8 ± 43.5	39.2 ± 33.7	45.1 ± 27.9	42.8 ± 35.4	.428	.030	.120
Grade III Freq, Hz	0.43 ± 0.26	0.32 ± 0.23	0.40 ± 0.25	0.30 ± 0.20	.779	.004	.059
Grade III Amp, N	22.6 ± 21.1	8.9 ± 9.3	13.1 ± 15.1	11.8 ± 11.0	.026‡	.214	.625
Grade IV MPF, N	51.6 ± 45.7	51.4 ± 44.8	49.6 ± 30.1	49.5 ± 37.2	.950	.000	.050
Grade IV Freq, Hz	0.37 ± 0.25	0.30 ± 0.23	0.34 ± 0.32	0.35 ± 0.25	.460	.026	.111
Grade IV Amp, N	16.2 ± 16.3	6.6 ± 5.5	11.8 ± 12.9	9.8 ± 8.6	.102	.122	.371

Abbreviations: PA, Posterior to Anterior; N, Newton; MPF, Mean Peak Force; Freq, Oscillation Frequency; Amp, Peak to Peak Amplitude; Hz, Hertz

*Values are mean ± SD for the absolute value of the difference between the subjects and expert physical therapist

†Values are for the interaction effect of Time (Pre and Post Practice) x Device (With and Without)

‡Significantly different at $P < .05$

Figure 5. Comparison of R2 force student performance (absolute value of the difference between student and expert, N) between pre-practice and post-practice time frame with and without the real-time feedback device ($P = .013$). Vertical lines represent ± 1 standard error from the mean.

Figure 6. Comparison of Grade III peak to peak amplitude force student performance (absolute value of the difference between student and expert, N) between pre-practice and post-practice time frame with and without the real-time feedback device ($P = .026$). Vertical lines represent ± 1 standard error from the mean.

without any prior manual therapy training. Our study found that real-time, augmented feedback was beneficial to the learning and retention of the complex motor skill of lumbar spine mobilization. The visual and

auditory feedback provided by the loadpad device was given concurrently during practice. Additionally, students were able to receive terminal feedback on all trials during each practice period. Previous studies have

shown that subjects receiving either concurrent or terminal feedback demonstrated improved performance, decreased variability, and improved retention when learning mobilization techniques [49,51,53,69,70]. The subjects in our study also demonstrated improvement in these three aspects when receiving concurrent and terminal feedback.

Variability in joint mobilization skill performance between expert and novice practitioners

Previous research has shown there is a wide variation between students and trained physical therapists when applying manual forces to the spine during mobilization [33–39]. However, when provided with objective feedback, student performance can become more accurate and consistent [9,40–44]. The results of our study support these conclusions and are represented in Table 3. High variability in force production, speed, and amplitude was exhibited by the students at the beginning of the study compared with the expert as evidenced by large standard deviations from the mean. By the end of the study, however, the students' larger standard deviation values decreased, whereas as the expert's smaller standard deviation values for each variable remained approximately the same. This finding is promising, as the students practiced only a total of two hours (1 hour with the device and 1 hour without it) and yet began to quickly decrease their variability.

Joint mobilization teaching methods

Traditional teaching methods for learning joint mobilization skills have consisted of an expert instructor demonstrating techniques followed by student practice sessions [21,29,30,58,59]. During these sessions, students typically receive limited objective feedback about the forces applied due to large faculty-student ratios and may continue to practice erroneous motor

patterns that adversely affect skill mastery. Previous studies have explored more non-traditional methods of teaching joint mobilization with promising results [29,31,58,59,71]. Gonzalez-Sanchez et al [29] and Triano et al [58,59] utilized quantitative feedback devices with subjects and found that those teaching methods were superior to the traditional approach. However, an expert clinician is still needed in the learning process to provide a reference standard for joint mobilization forces [71,72]. Devices that provide quantitative feedback allow an expert clinician to share objective force parameters with a multitude of students in a classroom setting. Our study supports the use of implementing similar devices into the teaching of joint mobilization, which can provide the learner with quantitative feedback on how to simulate expert practice.

Limitations

Although multiple grades and forces of mobilization were examined in this study, our findings are limited to the central PA mobilization on the L3 lumbar vertebra. It is unknown if these findings can be generalized to other mobilization techniques in the lumbar spine or to other peripheral or spinal joints. Additionally, the order of force parameter practice was not randomized. This may have biased the results as Grade IV force parameters were always performed after Grade III. The central PA mobilization technique was chosen in this study to be able to compare our findings to other research on this same technique. The specific student population of truly novice learners was selected to eliminate the possible effects of varying levels of practical experience of students at different levels of learning.

Additional limitations include a small sample size of subjects who are all Year 1 DPT students at a single institution. Recruiting a larger sample of students from multiple institutions may reveal different results and make the findings more generalizable. Furthermore, all mock patients in this study were asymptomatic for lumbar pain and pathology. Therefore, no conclusions can be drawn about how students might perform on symptomatic patients in a clinical setting.

The majority of subjects felt confident using technology which provided augmented feedback to enhance their learning. Additionally, 22 out of 24 subjects felt that the real-time feedback would help them learn and retain manual skills. Twelve subjects self-identified as having a hands-on learning style, while 12 identified as having a combination style of hands-on with visual and auditory input. (See Table 1) These factors may limit the applicability of these findings to individuals with different characteristics.

Finally, we chose a crossover study design due to its efficiency and practicality in an academic setting. Choosing a different study design in which the two

Table 3. Expert and subject comparison from the beginning to the end of the study.

Lumbar Spine Central PA Mobilization Parameters	Beginning of the Study*		End of the Study*	
	Expert	Subjects	Expert	Subjects
R1 Force, N	76.2 ± 13.4	84.9 ± 48.2	67.7 ± 14.3	79.4 ± 25.8
R2 Force, N	180.6 ± 27.8	176.1 ± 75.4	156.4 ± 26.4	183.6 ± 50.2
Grade III MPF, N	117.4 ± 19.4	154.6 ± 57.3	107.5 ± 21.1	146.1 ± 37.9
Grade III Frequency, Hz	1.4 ± 0.09	0.97 ± 0.32	1.4 ± 0.10	1.3 ± 0.27
Grade III Amplitude, N	29.3 ± 4.9	52.1 ± 25.0	21.8 ± 4.1	22.1 ± 6.1
Grade IV MPF, N	104.7 ± 18.2	147.4 ± 51.1	94.1 ± 21.7	144.4 ± 39.4
Grade IV Frequency, Hz	1.5 ± 0.11	1.4 ± 0.53	1.3 ± 0.27	1.5 ± 0.34
Grade IV Amplitude, N	21.9 ± 3.7	36.6 ± 20.2	14.4 ± 3.1	17.9 ± 6.2

Abbreviations: PA, Posterior to Anterior; MPF = Mean Peak Force; N, Newton; Hz, Hertz

*Values are mean ± SD for the actual forces and frequencies applied to mock patients in the study

groups are completely separate from each other may have elicited different results.

Future research

Future research exploring mobilization and manipulation skills for different joints and all spinal levels would provide important information about how students learn and retain this essential skill set in entry-level education. In addition, quantification of forces produced with these joint mobilization and manipulation techniques would be helpful in better understanding how they are applied not only in the classroom with asymptomatic individuals, but also in the clinic with actual patients. Different feedback schedules and methods could also be explored to determine the optimal ones for learning joint mobilization with a real-time feedback device. Furthermore, understanding force quantification of various joints can provide insight into manual therapy dosing for a desired treatment effect and overall effectiveness of care.

Conclusion

Real-time objective feedback using a direct force measurement device is beneficial for physical therapy students learning lumbar spine joint mobilization. Students who used the feedback device performed significantly better than without the device when applying R2 forces and Grade III amplitude forces to the lumbar spine. Practice alone was also beneficial in reducing the variability in novice student performance.

Acknowledgments

The authors wish to thank Steve Allison and David Fike for their contributions in the statistical analysis of the manuscript. We also wish to thank Jonathan Koborsi, Tommy Lee, Kelly Miller, and Catherine Shaw for their contributions with data collection.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This study was funded in part by the University of the Incarnate Word (UIW), Office of Research and Graduate Studies. Additional donations in kind were provided by the UIW School of Physical Therapy to complete the study.

This study was reviewed and accepted by the Institutional Review Board at the University of the Incarnate Word, San Antonio, TX. The IRB deemed this study as non-clinical as the purpose was to examine the effect only on the providers (for example, provider knowledge or attitudes). In this study the effect of real-time feedback on the learning of a manual therapy technique was studied. Therefore, it was not included in a public trials registry.

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References

- [1] Guide to Physical Therapist Practice 3.0. Alexandria, VA: American Physical Therapy Association; 2014. [cited 2019 Sep 30]. Available from: <http://guidetoptpractice.apta.org/>
- [2] American Physical Therapy Association Manipulation Task Force MEC. Manipulation Education Manual for Physical Therapist Professional Degree Programs. Alexandria, VA: American Physical Therapy Association; 2004. [cited 2019 Sep 20]. Available from: http://www.apta.org/uploadedFiles/APTAorg/Educators/Curriculum_Resources/APTA/Manipulation/ManipulationEducationManual.pdf
- [3] Bjornsdottir SV, Kumar S. Posteroanterior motion test of a lumbar vertebra: accuracy of perception. *Disabil Rehabil*. 2003;25:170–178.

- [4] Chiradejnant A, Maher CG, Latimer J. Objective manual assessment of lumbar posteroanterior stiffness is now possible. *J Manipulative Physiol Ther.* 2003;26:34–39.
- [5] Gautam N, Sharma S. Effect of concurrent quantitative feedback training on intra-rater and inter-rater reliability of grade III mobilization over fourth lumbar spinous process. *Indian J Physiother Occup Ther.* 2011;5(1):80–84.
- [6] Kulig K, Landel RF, Powers CM. Assessment of lumbar spine kinematics using dynamic MRI: a proposed mechanism of sagittal plane motion induced by manual posterior-to-anterior mobilization. *J Orthop Sports Phys Ther.* 2004;34(2):57–64.
- [7] Powers CM, Beneck GJ, Kulig K, et al. Effects of a single session of posterior-to anterior spinal mobilization and press-up exercise on pain response and lumbar spine extension in people with non-specific low back pain. *Phys Ther.* 2008;88(4):485–493.
- [8] Powers CM, Kulig K, Harrison J, et al. Segmental mobility of the lumbar spine during a posterior to anterior mobilization: assessment using dynamic MRI. *Clin Biomech.* 2003;18(1):80–83.
- [9] Sheaves EG, Snodgrass SJ, Rivett DA. Learning lumbar spine mobilization: the effects of frequency and self-control of feedback. *J Orthop Sports Phys Ther.* 2012;42(2):114–124.
- [10] Shirley D, Ellis E, Lee M. The response of posteroanterior lumbar stiffness to repeated loading. *Man Ther.* 2002;7(1):19–25.
- [11] Shum GL, Tsung BY, Lee RY. The immediate effect of posteroanterior mobilization on reducing back pain and the stiffness of the lumbar spine. *Arch Phys Med Rehabil.* 2013;94(4):673–679.
- [12] Snodgrass SJ, Rivett DA, Robertson VJ. Manual forces applied during posterior-to-anterior spinal mobilization: a review of the evidence. *J Manipulative Physiol Ther.* 2006;29:316–329.
- [13] Hengeveld E, Banks K. Maitland's vertebral manipulation. 8th ed. Philadelphia (PA): Elsevier; 2014.
- [14] Jull G, Moore A, Falla D, et al. Grieve's modern musculoskeletal physiotherapy. 4th ed. Philadelphia (PA): Elsevier; 2015.
- [15] Maitland Australian Physiotherapy Seminars. MT-2: basic Spinal. Cutchogue (NY): Cayuga Professional Education; 2009.
- [16] Maitland Australian Physiotherapy Seminars. MT-2: intermediate spinal. Cutchogue (NY): Cayuga Professional Education; 2013.
- [17] Wise C. Orthopaedic manual physical therapy: from art to evidence. Philadelphia (PA): FA Davis; 2015.
- [18] Ben-Sorek S, Davis CM. Joint mobilization education and clinical use in the United States. *Phys Ther.* 1988;68(6):1000–1004.
- [19] Boissonnault W, Bryan JM, Fox KJ. Joint manipulation curricula in physical therapist professional degree programs. *J Orthop Sports Phys Ther.* 2004;34:171–181.
- [20] Bryan JM, McClune LD, Romito S, et al. Spinal mobilization curricula in professional physical therapy education programs. *J Phys Ther Educ.* 1997;11:11–15.
- [21] Flynn TW, Wainner RS, Fritz JM. Spinal manipulation in physical therapist professional degree education: a model for teaching and integration into clinical practice. *J Orthop Sports Phys Ther.* 2006;36:577–587.
- [22] Sizer PS, Felstehausen V, Sawyer S, et al. Eight critical skills sets required for manual therapy competency: a Delphi study and factor analysis of physical therapy educators of manual therapy. *J Allied Health.* 2007;36(1):30–40.
- [23] American Physical Therapy Association. Minimum required skills of physical therapist graduates at entry-level: BOD G11-05-20-49 [Guideline]. Alexandria (VA): American Physical Therapy Association; 2009 [updated 2009 Dec 14; cited 2019 Aug 22]. Available from: https://www.apta.org/uploadedfiles/aptaorg/about_us/policies/bod/education/minreqskillsptgrad.pdf
- [24] Commission on Accreditation in Physical Therapy Education. CAPTE accreditation handbook. Alexandria (VA): American Physical Therapy Association; 2019 [updated 2019 May 30; cited 2019 Aug 22]. Available from: <http://www.capteonline.org/AccreditationHandbook/Updated>
- [25] Bronfort G, Haas M, Evans R, et al. Evidence-informed management of chronic low back pain with spinal manipulation and mobilization. *Spine J.* 2008;8:213–225.
- [26] Cherkin DC, Sherman KJ, Deyo RA, et al. A review of the evidence for the effectiveness, safety, and cost of acupuncture, massage therapy, and spinal manipulation for back pain. *Ann Intern Med.* 2003;138:898–906.
- [27] Ernst E. Adverse effects of spinal manipulation: a systematic review. *J R Soc Med.* 2007;100:330–338.
- [28] Noteboom JT, Little C, Boissonnault W. Thrust joint manipulation curricula in first-professional physical therapy education: 2012 update. *J Orthop Sports Phys Ther.* 2015;45(6):471–476.
- [29] González-Sánchez M, Ruiz-Muñoz M, Ávila-Bolívar AB, et al. Kinematic real-time feedback is more effective than traditional teaching method in learning ankle joint mobilisation: a randomised controlled trial. *BMC Med Educ.* 2016;16(1):261.
- [30] Petty NJ, Bach TM, Cheek L. Accuracy of feedback during training of passive accessory intervertebral movements. *J Man Manip Ther.* 2001;9(2):99–108.
- [31] Washmuth NB, Ross S, Bowens AN. Effect of motor learning theory-assisted instruction versus traditional demonstration on student learning of spinal joint manipulation. *Health Professions Educ.* 2019. DOI:10.1016/j.hpe.2019.05.004
- [32] Wise CH, Shenk RJ, Lattanzi JB. A model for teaching and learning spinal thrust manipulation and its effect on participant confidence in technique performance. *J Man Manip Ther.* 2016;24(3):141–150.
- [33] Chiradejnant A, Latimer J, Maher CG. Forces applied during manual therapy to patients with low back pain. *J Manipulative Physiol Ther.* 2002;25:362–369.
- [34] Gagnon DH, Longtin C, Berbiche D, et al. Do experienced physiotherapists and final year physiotherapy trainees apply similar force during posterior-to-anterior lumbar mobilization techniques? *Man Ther.* 2016;21:287–291.
- [35] Harms MC, Bader DL. Variability of forces applied by experienced therapists during spinal mobilization. *Clin Biomech.* 1997;12:393–399.
- [36] Snodgrass SJ, Rivett DA, Robertson VJ, et al. A comparison of cervical spine mobilization forces applied by experienced and novice physiotherapists. *J Orthop Sports Phys Ther.* 2010;40:392–401.
- [37] Snodgrass SJ, Rivett DA, Robertson VJ, et al. Cervical spine mobilization forces applied by physiotherapy students. *Physiotherapy.* 2010;96:120–129.
- [38] Snodgrass SJ, Rivett DA, Robertson VJ, et al. Forces applied to the cervical spine during posteroanterior mobilization. *J Manipulative Physiol Ther.* 2009;32:72–83.
- [39] van Zoest GG, Staes FF, Stappaerts KH. Three dimensional manual contact force evaluation of graded perpendicular push force delivery by second-year

- physiotherapy students during simple feedback training. *J Manipulative Physiol Ther.* 2007;30:438–449.
- [40] Keating J, Matyas TA, Bach TM. The effect of training on physical therapists' ability to apply specified forces of palpation. *Phys Ther.* 1993;73:45–53.
- [41] Lee M, Moseley A, Refshauge K. Effect of feedback on learning a vertebral joint mobilization skill. *Phys Ther.* 1990;70:97–104.
- [42] Snodgrass SJ, Odelli RA. Objective concurrent feedback on force parameters improves performance of lumbar mobilisation, but skill retention declines rapidly. *Physiotherapy.* 2012;98(1):47–56.
- [43] Snodgrass SJ, Rivett DA, Robertson VJ, et al. Real-time feedback improves accuracy of manually applied forces during cervical spine mobilisation. *Man Ther.* 2010;15:19–25.
- [44] Triano JJ, Scaringe J, Bougie J, et al. Effects of visual feedback on manipulation performance and patient ratings. *J Manipulative Physiol Ther.* 2006;29:378–385.
- [45] Gorgos KS, Wasyluk NT, Van Lunen BL, et al. Inter-clinician and intra-clinician reliability of force application during joint mobilization: A systematic review. *Man Ther.* 2014;19(2):90–96.
- [46] 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.
- [47] Lee RYW, McGregor AH, Bull AMJ, et al. Dynamic response of the cervical spine to posteroanterior mobilisation. *Clin Biomech.* 2005;20:228–231.
- [48] Kope R, O'Brien J, Sadi J, et al. Quantifying performance metrics of cervical spine mobilization for improved education and clinical outcomes: early experience with a novel wearable device. *J Rehabil Assist Technol Eng.* 2018;20(5):1–8.
- [49] Cuesta-Vargas AI, González-Sánchez M, Lenfant Y. Inertial sensors as real-time feedback improve learning posterior-anterior thoracic manipulation: a randomized controlled trial. *J Manipulative Physiol Ther.* 2015;38(6):425–433.
- [50] 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.
- [51] Pasquier M, Cheron C, Dugas C, et al. The effect of augmented feedback and expertise on spinal manipulation skills: an experimental study. *J Manipulative Physiol Ther.* 2017;40(6):404–410.
- [52] Cook C, Turney L, Ramirez L, et al. Predictive factors in poor inter-rater reliability among physical therapists. *J Man Manip Ther.* 2002;10:200–205.
- [53] Descarreaux M, Dugas C, Lalanne K, et al. Learning spinal manipulation: the importance of augmented feedback relating to various kinetic parameters. *Spine J.* 2006;6(2):138–145.
- [54] Matyas TA, Bach TM. The reliability of selected techniques in clinical arthrometrics. *Aust J Physiother.* 1985;31:175–199.
- [55] Harms MC, Innes SM, Bader DL. Forces measured during spinal manipulative procedures in two age groups. *Rheumatology.* 1999;38:267–274.
- [56] Langshaw M. *Cervical spine mobilisation: the effect of experience and subject on dose* [dissertation]. Sydney: The University of Sydney; 2001.
- [57] Lardon A, Cheron C, Page I, et al. Systematic augmented feedback and dependency in spinal manipulation learning: a randomized comparative study. *J Manipulative Physiol Ther.* 2016;39(3):185–191.
- [58] Triano JJ, Rogers CM, Combs S, et al. Developing skilled performance of lumbar spine manipulation. *J Manipulative Physiol Ther.* 2002;25(6):353–361.
- [59] Triano JJ, Rogers CM, Combs S, et al. Quantitative feedback versus standard training for cervical and thoracic manipulation. *J Manipulative Physiol Ther.* 2003;26(3):131–138.
- [60] Triano JJ, Bougie J, Rogers C, et al. Procedural skills in spinal manipulation: do prerequisites matter? *Spine J.* 2004;4(5):557–563.
- [61] Threlkeld JA. The effects of manual therapy on connective tissue. *Phys Ther.* 1992;72:893–902.
- [62] Conradie M, Smit E, Louw M, et al. Do experienced physiotherapists apply equal magnitude of force during a grade I central PA mobilization on the cervical spine. *S Afr J Physiother.* 2004;60:18–25.
- [63] Smit E, Conradie M, Wessel J, et al. Measurement of the magnitude of force applied by students when learning a mobilization technique. *S Afr J Physiother.* 2003;59:3–8.
- [64] Silvernail JL, Gill NW, Teyhen DS, et al. Biomechanical measures of knee joint mobilization. *J Man Manip Ther.* 2011;19(3):162–171.
- [65] Tragord BS, Gill NW, Silvernail JL, et al. Joint mobilization forces and therapist reliability in subjects with knee osteoarthritis. *J Man Manip Ther.* 2013;21(4):196–206.
- [66] Willett E, Hebron C, Krouwel O. The initial effects of different rates of lumbar mobilizations on pressure pain thresholds in asymptomatic subjects. *Man Ther.* 2010;15:173–178.
- [67] Boulet JR, Gimpel JR, Dowling DJ, et al. Assessing the ability of medical students to perform osteopathic manipulative treatment techniques. *J Am Osteopath Assoc.* 2004;104(5):203–211.
- [68] Buckingham G, Das R, Trott P. Position of undergraduate students' thumbs during mobilization is poor: an observational study. *Aust J Physiother.* 2007;53(1):55–59.
- [69] Chang JY, Chang GL, Chien CJ, et al. Effectiveness of two forms of feedback on training of a joint mobilization skill by using a joint translation simulator. *Phys Ther.* 2007;87(4):418–430.
- [70] Vander Linden DH, Cauraugh JH, Greene TA. The effect of frequency of kinetic feedback on learning an isometric force production task in nondisabled subjects. *Phys Ther.* 1993;2:79–87.
- [71] Grädl-Dietsch G, Lübke C, Horst K, et al. Peyton's four-step approach for teaching complex spinal manipulation techniques—a prospective randomized trial. *BMC Med Educ.* 2016;16(1):284.
- [72] Knobe M, Holschen M, Mooij SC, et al. Knowledge transfer of spinal manipulation skills by student-teachers: a randomised controlled trial. *Eur Spine J.* 2012;21(5):992–998.