EDUCATION RESEARCH SERVICE

ORIGINAL ARTICLE

High-velocity, low-amplitude spinal manipulation training of prescribed forces and thrust duration: *A pilot study*

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Objective: High-velocity, low-amplitude spinal manipulation (HVLA-SM) may generate different therapeutic effects depending on force and duration characteristics. Variability among clinicians suggests training to target specific thrust duration and force levels is necessary to standardize dosing. This pilot study assessed an HVLA-SM training program using prescribed force and thrust characteristics.

Methods: Over 4 weeks, chiropractors and students at a chiropractic college delivered thoracic region HVLA-SM to a prone mannequin in six training sessions, each 30 minutes in duration. Force plates embedded in a treatment table were used to measure force over time. Training goals were 350 and 550 Newtons (N) for peak force and ≤150 ms for thrust duration. Verbal and visual feedback was provided after each training thrust. Assessments included 10 consecutive thrusts for each force target without feedback. Mixed-model regression was used to analyze assessments measured before, immediately following, and 1, 4, and 8 weeks after training.

Results: Error from peak force target, expressed as adjusted mean constant error (standard deviation), went from 107 N (127) at baseline, to 0.2 N (41) immediately after training, and 32 N (53) 8 weeks after training for the 350 N target, and 63 N (148), −6 N (58), and 9 N (87) for the 550 N target. Student median values met thrust duration target, but doctors' were >150 ms immediately after training.

Conclusion: After participation in an HVLA-SM training program, participants more accurately delivered two prescribed peak forces, but accuracy decreased 1 week afterwards. Future HVLA-SM training research should include follow-up of 1 week or more to assess skill retention.

Key Indexing Terms: Formative Feedback; Manipulation, Chiropractic; Motor Skills; Task Performance and Analysis

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INTRODUCTION

The performance of high-velocity, low-amplitude spinal manipulation (HVLA-SM) is a sensorimotor skill requiring neuromuscular coordination to perform. Practice of these complex tasks is necessary to develop the skill level of an experienced clinician.[1] HVLA-SM training traditionally has begun with learning theoretical concepts before moving to motor skill practice with qualitative instructor feedback.[2,3] Strategies used to provide feedback include partial practice, which includes doctor–patient positioning without a manipulative thrust, and complete practice, which includes delivering a manipulative thrust.[4–6] Students participating in complete practice are able to deliver HVLA-SM thrusts more like those of experienced clinicians when comparing rate of force production.[5] However, repeated practice of dynamic thrusts with human, simulated patients raises safety concerns.[7,8]

Force-sensing devices offer an objective method of evaluating HVLA-SM performance. Complete HVLA-SM practice can be accomplished with force-sensing technology incorporated into hand-interface devices or platform systems measuring thrust characteristics delivered to devices, humans, or mannequins functioning as simulated patients.[2–4] Using mannequins removes injury risk to patients[7,8] and provides additional training components compared to devices alone. Other potential benefits of using mannequins and force-sensing equipment include faster motor skill development, likely due to the greater potential for repeated practice,[5,9] and higher student confidence[4] and satisfaction.[10]

Differing HVLA-SM characteristics have the potential to affect physiology, including vertebral movement and neuromuscular responses. Electromyographic (EMG) muscle spindle response has been demonstrated to be most affected by the rate of force application, more so than peak or preload force,[11] indicating that peak force and rate of force loading may generate distinct physiologic responses and influence treatment effectiveness.

Force-sensing technology has demonstrated quantitative differences in HVLA-SM force delivery between students and experienced clinicians. Experienced clinicians deliver higher peak force thrusts with shorter duration compared to students; however, they do not deliver prescribed forces more accurately.[12] Moreover, peak thrust forces vary substantially among experienced clinicians.[13–16] Focused training methods may be necessary to develop the ability to deliver manipulation with specific biomechanical parameters. The ability to deliver prescribed manipulative forces consistently also is necessary to address some questions related to treatment dosing, which can be answered only by applying standardized manipulative forces and loading rates.[17–19]

Force-sensing technology has been used to train participants to deliver prescribed forces within wide ranges,[20] as a percentage of the clinician's maximum force,[21] and doubling or halving a clinician's typical force.[14] These training methods appear to decrease intra-clinician variability, but they do not address the problem of inconsistent force delivery among clinicians. HVLA-SM training to deliver peak force of a prespecified value also has been tested.[22–25] However, the studies have had limited follow-up to assess skill retention. Physiotherapy students have been trained previously to deliver specific forces and duration in oscillatory lumbar mobilization. However, skill retention after 1 week has been mixed,[26,27] suggesting that this may be important to assess during HVLA-SM training.

The current pilot study was developed to answer fundamental questions about how HVLA-SM training can be structured to help trainees achieve the ability to reproduce prespecified peak forces and thrust duration immediately and up to 8 weeks after training. The primary aims of this pilot study were to: (1) assess a standardized training plan for the delivery of HVLA-SM thrusts with prescribed peak force and thrust duration parameters and (2) describe the retention of these skills 1, 4, and 8 weeks after training.

METHODS

This project was approved by the Palmer College institutional review board. Study participants were recruited from Palmer College of Chiropractic (Davenport, IA). Individuals were recruited through campus advertisements on hallway monitors, e-mail communications, newsletters, and classroom announcements. Interested individuals contacted study personnel via e-mail or phone. A formal informed consent process, including a written informed consent document, was conducted.

Eligible participants included college faculty and staff who hold a Doctor of Chiropractic (DC) degree and students in the 7th or 8th trimester of a 10-trimester professional program at the time of recruitment. This student population was chosen to ensure availability for follow-up at 8 weeks after training and because students in this educational phase have received necessary theoretical and basic motor-skill training in a variety of spinal manipulation procedures.[2,28,29] Exclusion criteria included having prior training in delivering specified forces while performing thoracic HVLA-SM, a past or present injury that prevents delivering an HVLA-SM thrust, or a plan to move from the local area in the following 3 months.

At the baseline visit, demographic information was collected consisting of self-reported sex, age, height, weight, and trimester level (for students). DCs reported how often they engaged in patient care, years of experience, and if they used HVLA-SM. Participants were oriented to the training room and procedures, including demonstration of a bilateral thenar contact applied to points marked at approximately the 4th thoracic vertebral level on a training mannequin (FSTT Human Analog Mannequin [HAM]; Canadian Memorial Chiropractic College [CMCC], Toronto, Ontario, Canada), and explanation of other relevant research equipment. The human analog mannequin used was designed to mimic soft tissue compliance of humans[30] and has been used in previous training programs.[14]

The mannequin was positioned on a custom-built treatment table with adjustable height over an embedded force plate that measures three-dimensional forces (Model No. 4060-NC; Bertec, Inc, Columbus, OH). During orientation, participants chose their preferred table height and side of the mannequin on which to stand to deliver HVLA thrusts, and these preferences were replicated for all subsequent training and assessment visits.

After orientation, participants were instructed to deliver five practice thrusts using their typical force without further prespecifying force or thrust duration targets. After completing all five practice thrusts, the range of peak forces and thrust durations were verbally communicated to the participants. Practice thrusts were immediately followed by the baseline assessment.

Assessments

Participants were blind to forces recorded at all assessments. The goal of assessments was to deliver 10 consecutive thrusts with a duration of <150 ms at each of two different force targets, 350 and 550 N, in the posterior to anterior (P-A) direction. Recent literature reports that mean mid to lower thoracic HVLA-SM peak force values of experienced clinicians range from approximately 350 N[14,31] to 550 N[32,33] in the P-A direction. This range is consistent with previous literature, as reviewed by Downie et al.[15] Current studies on transmission of HVLA-SM forces suggest that mostly normal (perpendicular) forces are transmitted to the spine through the skin-fascia interface and that normal forces are responsible for producing most vertebral movement[34,35] and activation of muscle spindles.[36] Therefore, only P-A forces were targeted and measured in this study. The primary training goals of this study were the peak force targets. Since speed is commonly reduced when accuracy is increased,[21] a thrust duration cutoff goal was added. The thrust duration target was set to <150 ms, based on levels commonly delivered by experienced clinicians[37,38] and research showing a greater physiologic response by muscle spindles between 75 and 150 ms.[39]

Training Program

Training included six 30-minute sessions, consisting of as many blocks of 10 thrusts as time allowed, which typically included 60–100 thrusts. Participants were allowed to complete the training sessions at their convenience, but were required to do so within 4 weeks of baseline. Training was conducted at the Palmer Center for Chiropractic Research (Davenport, IA). Training sessions included an individual participant and a single study team member (ZS), a DC with additional formal graduate training in clinical research, who recorded measurements and provided force and time measurement feedback. Participants were not coached on how to perform or adapt thrusts to achieve the desired parameters.

In an effort to enhance learning,[21] peak force training began with blocked variable practice characterized by practicing 10 repetitions of HVLA-SM thrusts focused on achieving peak force values of either 350 or 550 N. The program began to transition to random variable practice at the 3rd training session where each practice set of 10 thrusts included 350 and 550 N target peak forces. The 5th and 6th training sessions consisted of randomly ordered blocks of 10 thrusts with half targeting 350 N and half targeting 550 N.

Feedback given during training sessions consisted of a visual display of the force-time profile on a computer monitor and verbal communication of peak force achieved immediately following each thrust. The thrust duration was calculated manually and verbally communicated to the participant periodically during each 10-thrust practice set.

Data Collection

Data were measured using Motion Monitor software and a 16-bit analog-to-digital system (Innovative Sports Training, Inc, Chicago, IL). Data were collected at a sampling rate of 1000 Hz and exported as ASCII text files before further reduction and analysis.

A 20-Hz low-pass digital filter was applied to smooth the force-time curves for analysis. A search algorithm was used to determine key time points including the application of preload force, initiation of the thrust, peak force, and end of the thrust, which were extracted from the force-time data files using a semi-automated MATLAB program with visual inspection (Version 2015a; MathWorks, Natick, MA).

Adverse Events

Adverse events, assessed at each study visit, were defined as any untoward medical occurrence that may present itself during the conduct of the study and that may or may not have a causal relationship with study procedures.[40] Adverse events were graded as: (1) mild, moderate, severe, or serious; (2) expected (disclosed in the Consent Form or part of an underlying disease) or unexpected (more serious than expected, or not disclosed in the Consent Form); and (3) definitely related to study activity, probably related, possibly related, unlikely related or unrelated.

Table 1 - Demographics of Students and DCs Participating in an HVLA-SM Training Program ($n = 16$)

	Student ($n = 8$)	DC ($n = 8$)
Age, years - median (IQR)	29 (27–32)	57 (33–63)
Female	4	4
Race		
White	8	7
Multiple races	0	1
Ethnicity		
Not Hispanic or Latino	7	8
Hispanic or Latino	1	0
Height, inches - median (IQR)	70 (66–71)	66 (64–68)
Weight, pounds - median (IQR)	185 (170–210)	170 (124–189)
Current trimester		
7th	5	NA
8th	3	NA
Clinical experience, years - median (IQR)	NA	25 (6–37)
Patient treatment frequency		
Not at all	NA	2
Less than half-time	NA	5
Full-time	NA	1
Use HVLA-SM	NA	8

n reported unless otherwise noted; NA: not applicable.

Data Analysis

Descriptive statistics were calculated using SPSS (v21.0; IBM, Chicago, IL) including counts, means, and standard deviations for normally distributed variables, and median and interquartile range (IQR) for nonnormally distributed variables. Amount of error from target peak force, expressed as constant error (CE) and defined as the force achieved minus the target force value, was calculated for each force target at each assessment. CE was chosen as the primary outcome over absolute error because it identifies whether mean forces were delivered above, below, or equally above and below target across participants. Additionally, since this study focused on accuracy across participants, variable error, which shows variability within participants, was not calculated. SAS, version 9.4 (SAS Institute, Inc, Cary, NC, USA), was used to conduct a mixed-effects regression model analysis with an unstructured covariance matrix for each target force to produce adjusted mean CE values and their respective adjusted 95% confidence intervals (CIs). The regression analysis was used to adjust for repeated measures over time. Model assumptions were verified using exploratory data analysis.

RESULTS

Table 1 outlines participant demographics. A total of 31 individuals (22 students, 9 faculty/staff) expressed interest in the study. Of 16 participants enrolled (8 DCs and 8 students, half of each group female), 14 completed all five assessments; 1 participant missed the 4- and 8-week post-training assessments due to an adverse event, while another missed assessments immediately and at 1 and 4 weeks after training due to scheduling conflicts. Most DC

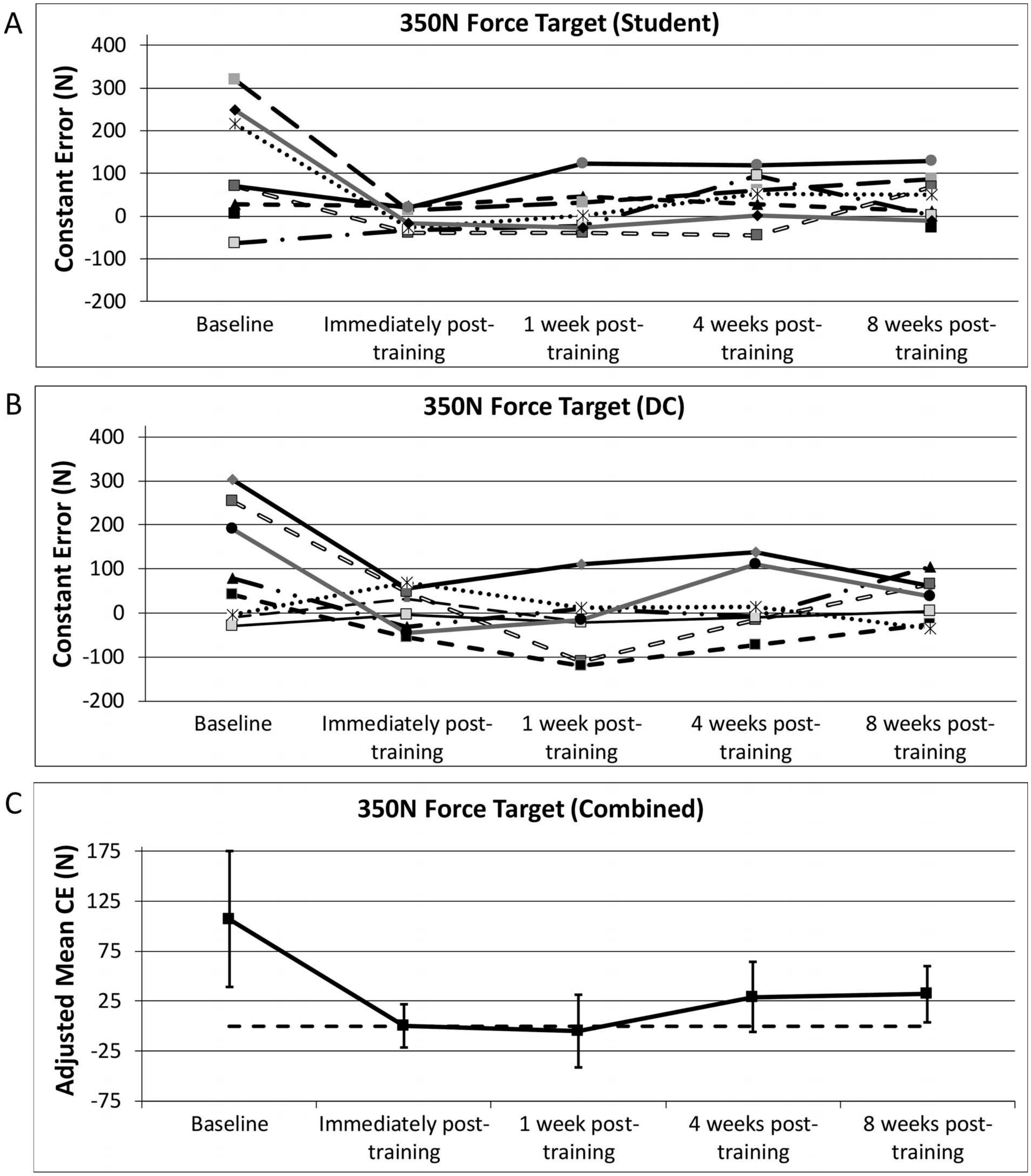

Figure 1 - (A) Student constant error from 350 N force target by assessment time point ($n = 8$). Each line represents data generated by a single student over time. (B) Doctor of chiropractic constant error from 350 N force target by assessment time point ($n = 8$). Each line represents data generated by a single DC over time. (C) Adjusted mean constant error from 350 N force target of students and DCs ($n = 16$). *Error bars*: 95% CIs. The *horizontal dashed line* marks zero mean constant error.

participants were engaged in patient care less than half-time, while all stated that they use HVLA-SM. The amount of clinical experience varied with a median of 25 years and IQR of 6 to 37 years.

There was no significant difference between students and DCs in mean peak force CE at the 350 or 550 N targets. Figures 1 and 2 graphically display individual CE and combined adjusted mean CE at each assessment time point for 350 and 550 N. Table 2 shows the results of the mixed-model regression analysis. Participants were able to most accurately deliver the target force immediately after training, as shown by the adjusted mean CE values,

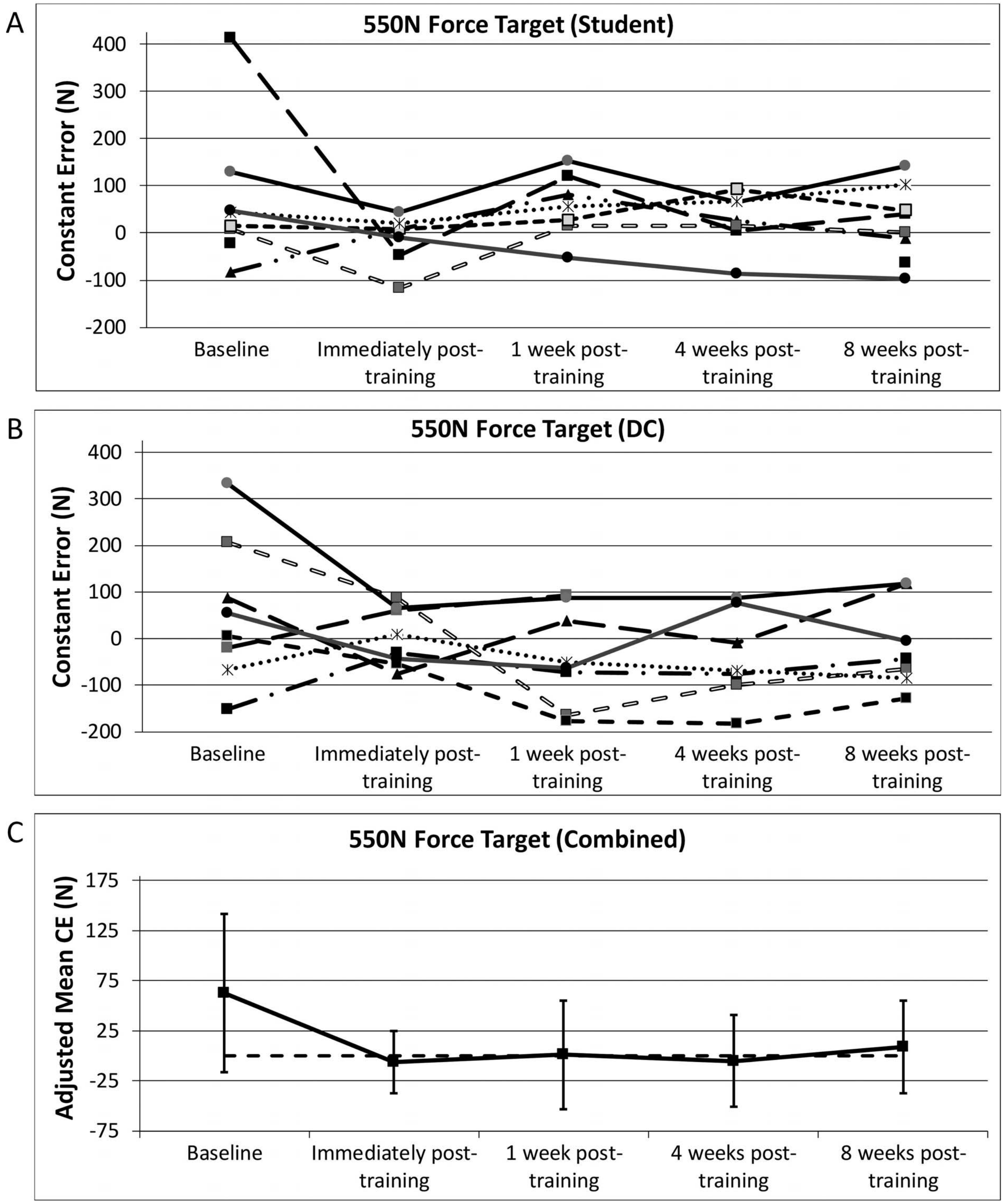

Figure 2 - (A) Student constant error from 550 N force target by assessment time point ($n = 8$). Each line represents data generated by a single student over time. (B) DC constant error from 550 N force target by assessment time point ($n = 8$). Each line represents data generated by a single DC over time. (C) Adjusted mean constant error from 550 N force target of students and DCs ($n = 16$). *Error bars*: 95% CIs. The *horizontal dashed line* marks zero mean constant error.

standard deviations, and associated adjusted 95% CIs. As time from immediately after training increased, the consistency across participants in peak force delivery reduced, as shown by the increase in standard deviations and spread of the CIs; mean values did not return to baseline levels 8 weeks after training, however.

Table 3 shows students and DCs thrust duration by assessment time point. Student median thrust duration

Table 2 - Adjusted Mean CE and Adjusted 95% CIs by Assessment Time Point ($n = 16$)

Assessment	Adjusted CE, N - Mean (SD)	Adjusted 95% CI
350 N force target[a]		
Baseline	107 (127)	40–175
Immediately after training	0.2 (41)	−22–22
1 week after training	−5 (68)	−41–31
4 weeks after training	29 (67)	−6–65
8 weeks after training	32 (53)	4–60
550 N force target[b]		
Baseline	63 (148)	−16–142
Immediately after training	-6 (58)	−37–25
1 week after training	1 (100)	−52–55
4 weeks after training	−5 (86)	−51–41
8 weeks after training	9 (87)	−38–55

[a] $F_{(4,15)} = 4.0$.
[b] $F_{(4,15)} = 0.94$.

stayed relatively consistent for both force targets, while DCs thrust duration was greater immediately after training than at baseline. The DCs median thrust duration returned to <150 ms at 1 week after training assessment for the 350 N target, but not until the 4-week post-training assessment for the 550 N target.

Five adverse events were judged as related to study activities (four mild and one moderate). The moderate event included wrist pain that lasted longer than expected and resulted in discontinuing study activities at the 4-week follow-up. The four mild events included transient thoracic muscle tightness and nonpainful crepitus in the right arm, both possibly related. One probably related mild event involved transient lower extremity muscle discomfort. One definite event involved knee pain from leaning/contacting the table during training, which was resolved by padding the contact area of the table.

Table 3. - Thrust Duration of Students and DCs by Assessment Time Point ($n = 16$)

	Thrust Duration, ms - Median (IQR)	
Assessment	Student ($n = 8$)	DC ($n = 8$)
350 N force target		
Baseline	113 (101–139)	132 (93–138)
Immediately after training	106 (105–137)	158 (126–198)
1 week after training	112 (99–134)	135 (103–192)
4 weeks after training	122 (108–124)	125 (102–163)
8 weeks after training	118 (105–140)	132 (95–161)
550 N force target		
Baseline	115 (105–133)	135 (106–160)
Immediately after training	107 (105–113)	152 (130–171)
1 week after training	109 (97–113)	158 (105–175)
4 weeks after training	101 (96–116)	140 (106–166)
8 weeks after training	109 (100–136)	140 (116–160)

DISCUSSION

The aims of this pilot study were to assess the feasibility of conducting an HVLA-SM training program and to describe participant ability to achieve prescribed peak force targets within thrust duration limits immediately and up to 8 weeks after training. Aspects of feasibility specifically assessed included recruitment and safety. We were able to recruit chiropractors and students at a chiropractic college to participate. Fifteen participants completed all six training sessions and one completed five sessions. Of 16 participants, 14 completed all follow-up assessments.

It has been hypothesized that doctors of chiropractic vary the level of peak force delivered during an HVLA-SM thrust depending on patient presentation.[2] However, due to the large peak force variability among clinicians,[13–16] it is unlikely that those forces are consistent across clinicians for similar patient presentations without specific training. Previous HVLA-SM training programs have largely focused on intra-clinician consistency (consistency in the ability to deliver force levels unique to themselves rather than for a specific patient presentation). Participants in this pilot study showed an increased between-participant consistency in the ability to deliver prescribed peak forces after a six-session training program. Mean values delivered by participants were within 10 N of target goal immediately after training, with a smaller standard deviation. Similar to findings reported by Snodgrass and Odelli,[26] who assessed the ability of physiotherapist students to deliver mobilization forces, participants in this study were not able to deliver forces as accurately 1, 4, and 8 weeks after training. Accuracy in HVLA-SM peak force delivery decreased the first week after training and continued to decrease at subsequent follow-ups, suggesting skill retention may degrade over time.

Our findings suggested assessing retained ability to deliver HVLA-SM thrusts with prespecified forces is necessary beyond a period of 1 week. Some HVLA-SM studies have evaluated the ability of clinicians to generate prespecified forces and, before this pilot study, the maximum follow-up timeframe was 1 week after training.[24] Future studies may address this gap by assessing skill retention over time with additional instruction, such as instructor feedback, video feedback, a comparative reference for visual feedback, or modifying the number and frequency of practice thrusts and training sessions. Gudavalli et al.[17–19] demonstrated that the recertification of ability to deliver prespecified forces using a low velocity manipulation may be necessary to maintain skill over time, which may generalize to HVLA-SM performance.

Although delivering slower thrusts when attempting to match a prescribed force is common when learning this motor task,[21] student participant thrust durations were quicker immediately after training than at baseline. For experienced clinicians, slower durations were noted. The discrepancy between student and experienced clinician thrust duration suggests there may be a difference in how students, who are still learning subtle coordination aspects of HVLA-SM, adapt to and learn the ability to deliver prescribed forces compared to clinicians whose motor skills are perhaps more ingrained. Marchand et al.[22] noted that the level of preload force applied was predictive of loading rate, suggesting that training prescribed preload force together with peak force may lead to an increased consistency of thrust duration.[22] Additional study is needed to better understand these phenomena.

Limitations

Because no control group was used to compare changes in accuracy over time, it cannot be confirmed that improved accuracy was the direct result of the training program. There also was a small sample size. The target force and duration goals chosen were based on the mean peak forces of experienced clinicians and a thrust duration thought to lead to greater muscle spindle activation. At this time, it is unclear what level or range of force or thrust duration leads to optimal clinical outcomes.

Visual feedback of force production was limited. Participants were shown an auto-calibrated force-time profile for each thrust without a simultaneous reference to compare against. This did not allow for visual feedback that would allow participants to comparatively see graphical differences between training thrusts. The Motion Monitor software displayed only the peak force value for each thrust during training. Because the thrust duration was manually calculated, less feedback on thrust duration was provided to increase the number of practice thrusts in the 30-minute training sessions.

This study focused on assessing a training program using force-sensing technology to develop or refine motor skills and application to a mannequin. It was not designed to address clinical components of HVLA-SM training, such as indications, contraindications, or adaptation of treatment with regard to understanding diagnosis and positions of palliation and provocation. Without including clinical decision-making into motor skill training, students may be less likely to recognize how or when to apply HVLA-SM appropriately in clinical encounters.[41]

Conclusion

HVLA-SM training program participants delivered two distinct prescribed peak forces more accurately immediately after training; however, accuracy reduced within 1 week and continued to decrease at subsequent follow-ups. Mean peak force values were closer to target goals at all follow-ups than at baseline. Future study of HVLA-SM training of prescribed forces should include follow-up over time and evaluate additional strategies to improve retention.

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