Reaction Force Magnitude and Orientation During Supine Thoracic Spine Thrust Manipulation: An Exploratory Analysis and Reliability of Preload and Impulse Phase

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Abstract

Objective: The main purpose of this study was to explore specific kinetic parameters during supine thoracic thrust manipulation and to analyze task reliability and differences between various practitioners.

Methods: Kinetic parameters were assessed by examining ground reaction force magnitude and orientation (on the basis of the zenithal angle) using force platforms. The manipulative procedure (consisting of the application of 3 preloads followed by 1 single thrust adjustment) was performed by different practitioners at 3 sessions. Application of thrust was allowed for trained practitioners only. Preload force, peak force, and vector force orientation were compared between sessions and practitioners.

Results: Reliability analysis showed that practitioners achieved similar preload and peak force independent of the session, with comparable force orientation data. Differences between practitioners were observed for preload and peak force but not regarding the zenithal angle during the thrust phase.

Conclusion: This study is the first that explores kinetic parameters for supine thoracic thrust manipulation. Task repeatability was confirmed and several differences were observed between practitioners. Certainly, there is a need for further investigation examining both dynamic parameters (ie, velocity and accelerations) and the potential neurologic effect of such manipulative technique. (J Manipulative Physiol Ther 2020;00;1-9)

Key Indexing Terms: Spinal Manipulation; Thoracic Spine; Manipulative Therapy; Biomechanics

Introduction

Spinal manipulative technique has been demonstrated as a cost-effective treatment and is frequently used by health professionals to manage various musculoskeletal complaints. The thrust manipulation technique is typically described as a high-velocity, low-amplitude procedure (HVLA), which means a short-time force or moment application displaying minimal displacement of a target joint segment.

The mechanical profile of HVLA is characterized by different phases: the preload, the impulse, and the resolution phases. The preload phase corresponds to the positioning of the targeted segment to reach the critical load, the impulse phase is depicted by a sudden increase of the force magnitude to a peak over a short period, and the resolution period defines the decrease of the forces applied. Features of the HVLA manipulation (ie, type of technique, force rate, peak force) have been shown to yield various biomechanical and neurophysiological effects, such as joint gapping, specific joint kinematics, neuromuscular responses, and muscle spindle activity.

Earlier investigations have demonstrated the 3-dimensional (3D) force-time profile of the spinal manipulation, showing the occurrence of a primary force component and secondary shear forces of which the latter could characterize various technical skills among practitioners.

Manual forces applied have been analyzed during mobilization of the cervical, thoracic, and lumbar spine. According to a review study, inconsistency of manual force application has been concluded probably owing to the large number of factors such as the applied manual technique, the
hand position, or the method of measurement, among others. Likewise, thrust manipulation has demonstrated large variability of force application during cervical manipulation.12 On the contrary, moderate consistent peak force levels have been observed during thoracic manipulation using mannequin models.13

Despite previous investigations, to our best knowledge, there is no analysis regarding the forces applied during supine thoracic thrust manipulation (STTM). The objectives of this study were (1) to explore the reaction force (RF) magnitude and orientation during STTM, (2) to assess the reliability RF during preload and impulse, and (3) to analyze data obtained among different practitioners.

METHODS
Participant Sample
The present study enrolled 12 healthy participants, 4 female and 8 male (average age: 24 ± 2 years; mean height: 169 ± 5 cm; body mass index: 23.4 ± 2.2 kg/m²) for the exploratory analysis, and 6 were included for the reproducibility and reliability analysis.

Participants were excluded if they had any history of thoracic trauma or surgery, neurologic disease, asthma, scoliosis, hyperkyphosis, osteoporosis, or recent musculoskeletal thoracic pain.

The present protocol was approved by the ethical committee (P2015/553; B406001526691) of the academic hospital, and all participants provided their written informed consent.

Manipulation Procedure
Manipulation was performed following a stepwise process described earlier.14 The participant was lying in supine position with the arms crossed, his trunk on a force platform (see below). The practitioner stood on the side of the participant and rolled him to contact the target segment (fifth thoracic level) with his hand (thenar eminence). The contact point was against the transverse process. The participant was rolled back to the supine position onto the hand of the practitioner, who applied compression on the participant’s chest through his elbows and forearm (Fig 1). The manipulation procedure consisted of 3 preload trials followed by 1 single thrust adjustment. Only trained practitioners (TPs) were allowed to achieve the thrust delivering; the student practitioners (SPs) performed the preload only. The participant should not have been aware of any pain or discomfort.

The whole protocol consisted of 3 different manipulation sessions, for which sessions 1 and 2 were performed within the same day (separated by 2 hours), and session 3 was scheduled 6 months later owing to ethical purpose. Student practitioners and TP1 completed their respective protocol on the whole sample for the session 1 and on 6 participants for the remaining sessions, and TP2 achieved STTM protocol on 6 participants for all the sessions (Fig 2).

Data Acquisition and Processing
The measurement system consisted of 2 parallel force platforms (10000 Hz, AMTI Inc, Watertown, Massachusetts) synchronized with an optoelectronic motion capture system (Vicon Motion System Ltd, Oxford, UK). The force platforms were integrated into the floor surface to record the ground reaction force and separated by 2 cm to avoid interference. During experimentation, the participant was positioned with the pelvis and the trunk on each platform. Data were collected using the Nexus software.

Analyzed parameters consisted in ground reaction force magnitude (RF) and orientation that was examined for the trunk only.

Decomposition of RF gives 3D force components as Fz represents the perpendicular force component, whereas Fx and Fy represent mediolateral and cephalocaudal force components.

Fig 1. Participant and practitioner positioning during supine thoracic thrust manipulation.
components, respectively. Considering the influence of the participant’s trunk weight, the RF was corrected by subtracting the Fz component measured when the participant was lying alone on the force platform before the STTM procedure.

As the main RF orientation is vertical, the zenithal angle was computed to ease the interpretation of our results. The latter corresponds to the angle between the RF and the z-axis, and was computed as follows:

\[ \text{Azenith} = \cos^{-1}(F_z/RF) \]

Statistical Analysis

Regarding RF data, the mean value for each participant was calculated from the 3 sessions for each phase (ie, preload and impulse). A repeated-measures analysis of variance (ANOVA) was conducted to identify whether a significant main effect (ie, session or practitioner) and session × practitioner interaction was present. When ANOVA indicated a significant difference, Bonferroni post hoc tests were conducted to identify significant comparisons.

The root mean square error (RMSE) and coefficient of variation were computed to estimate the repeatability of the task during sessions.

Results

Reliability Analysis

Reliability analysis was considered on the RF resultant only. An ANOVA for repeated measures showed that there was no effect of repetition (\(P = .162\)), session (\(P = .304\)), repetition × session (\(P = .761\)), or session × practitioner interaction (\(P = .358\)) on RF magnitude during the preloading. This confirmed that each practitioner achieved similar preload during each maneuver independent of the session. Concerning the STTM impulse phase, comparable outcomes were observed for the peak RF magnitude confirming that thrust manipulation was similarly performed between sessions (\(P = .155\)) regardless of the TP (ie, session × TP interaction; \(P = .742\)).

For the preload phase, when the procedure was performed on the same day, the RMSE of RF resultant ranged from 6.3 N to 18.8 N. Considering between-day sessions, these errors ranged from 31.4 N to 79.0 N. This means that variations of RF ranged from 2% to 21%. For the peak force, RMSE (between sessions) was 27.9 N for TP2 and 103.8 N for TP1, which corresponds to 5% and 15%, respectively. Table 1 shows the mean RMSE (all sessions) for each RF components and resultant regarding preload and impulse.

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Regarding RF orientation during preload, no effect of repetition, session, or preload × practitioner interaction was found regarding the zenithal angle. This confirms that vertical orientation of RF was similar during repetitive preloading regardless the practitioner.

For the impulse phase, there was no effect of the session (\(P = .240\)) or significant interaction between session and practitioner (\(P = .052\)) on zenithal angle, meaning that vertical orientation of RF was similar over the different sessions irrespective of the practitioner.
Table 1. RMSE Obtained for Preload and Thrust for Each Practitioner

<table>
<thead>
<tr>
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<th>Preload</th>
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<th>Impulse</th>
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<tr>
<td></td>
<td>x</td>
<td>y</td>
<td>z</td>
<td>RF</td>
</tr>
<tr>
<td>SP1</td>
<td>3.8 (1.7)</td>
<td>3.0 (1.7)</td>
<td>15.2 (11.8)</td>
<td>15.3 (11.8)</td>
</tr>
<tr>
<td>SP2</td>
<td>6.5 (4.2)</td>
<td>4.2 (1.9)</td>
<td>14.1 (8.0)</td>
<td>13.8 (7.9)</td>
</tr>
<tr>
<td>TP1</td>
<td>5.2 (3.3)</td>
<td>5.3 (3.7)</td>
<td>10.0 (6.6)</td>
<td>10.1 (6.4)</td>
</tr>
<tr>
<td>TP2</td>
<td>3.1 (0.9)</td>
<td>2.1 (0.8)</td>
<td>7.2 (1.9)</td>
<td>7.4 (2.0)</td>
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RMSE are expressed in Newton with standard deviations.

RF, reaction force; RMSE, root mean square error; SP, student practitioner; TP, trained practitioner.

**RF Magnitude**

Table 2 depicts the magnitude of RF components for preload and impulse phase. The z component (Fz) was much larger compared with the remaining components, showing a main RF magnitude in the vertical direction for both preload and impulse phases. In average, FN was about 1% larger than the Fz component, which indicates a small involvement of shear force components during the task. Figure 3 depicts the RF 3D components during the application of 3 consecutive preloads follows by 1 thrust manipulation.

A significant effect of practitioner was demonstrated on RF resultant (F = 21.811, P = .00014) regarding the preload phase, for which post hoc test analysis revealed a significant larger magnitude between 1 student (SP2) and the remaining practitioners (Bonferroni test; P < .001). Regarding the entire procedure, RF was significantly larger (P < .0001) during the impulse compared with the preload phase with a preload force. The latter corresponded to 53% (±6 standard deviation) of the peak force.

In addition, by comparing TPs (Fig 4), a main effect was observed on RF resultant (P = .009).

After post hoc analysis, RF magnitude between TPs was significantly different for both preload (P = .0042) and thrust (P = .0009). TP1 showed systematic higher values than TP2.

**Reaction Force Orientation**

Zenithal angle data are showed in Table 3 regarding both preload and impulse phases. When TPs were compared, no significant effect was observed for preload (P = .206) and impulse (P = .052). Furthermore, the zenithal angle was not significantly different between the 2 phases (P = .087). In short, this means that the zenithal angle did not differ between practitioners mainly, and independently of the phase considered.

**DISCUSSION**

The purpose of this pilot study was to assess the feasibility of conducting a STTM procedure and to examine its biomechanical characteristics to help in understanding of STTM. Although this manipulative procedure is frequently proposed for treating various musculoskeletal conditions (ie, neck pain, cervicogenic headache),15-17 apart from the clinical effects, specific kinetic parameters (ie, force components and orientation) are poorly investigated in the literature. Four practitioners participated to the adjustment protocol over various sessions, 2 TPs (TP1 and TP2, respectively 10 and 20 years of expertise in joint manipulation and both active in their clinical practice), and 2 SPs (SP1 and SP2, fifth academic year of osteopathic education program).

Table 2. Average Force Data (Standard Deviation) Obtained During Preload and Thrust. RF and 3D Components of Force (Fx, Fy, Fz)

<table>
<thead>
<tr>
<th></th>
<th>Preload</th>
<th></th>
<th>Impulse</th>
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<tbody>
<tr>
<td></td>
<td>Fx</td>
<td>Fy</td>
<td>Fz</td>
<td>RF</td>
</tr>
<tr>
<td>SP1</td>
<td>47.1 (26.7)</td>
<td>31.1 (28.5)</td>
<td>375.4 (66.3)</td>
<td>380.6 (67.4)</td>
</tr>
<tr>
<td>SP2</td>
<td>30.5 (27.0)</td>
<td>0.9 (27.2)</td>
<td>468.7 (97.6)</td>
<td>471.3 (97.1)</td>
</tr>
<tr>
<td>TP1</td>
<td>10.8 (24.5)</td>
<td>15.6 (16.0)</td>
<td>379.8 (69.9)</td>
<td>381.3 (70.3)</td>
</tr>
<tr>
<td>TP2</td>
<td>30.3 (17.1)</td>
<td>–2.6 (14.1)</td>
<td>287.9 (39.5)</td>
<td>290.4 (38.3)</td>
</tr>
<tr>
<td>Total</td>
<td>31.1 (28.5)</td>
<td>12.8 (24.6)</td>
<td>395.8 (95.0)</td>
<td>399.0 (95.0)</td>
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3D, 3-dimensional; RF, reaction force; SP, student practitioner; TP, trained practitioner.
Usually HVLA provides 1 or several cavitation noises that are considered the purpose of the procedure.\textsuperscript{18,19} Besides, authors observed that larger peak force\textsuperscript{20} or acceleration\textsuperscript{21} was achieved when cavitation occurred. During the current STTM procedures, cavitation was present in more than 95% of the cases, but this feature was not examined in relation with the parameters analyzed.

In general, variability of force applied (ie, preload, peak force) during the manipulative procedure might be related to the technique, the target level, the practitioner, or the measurement method.\textsuperscript{22}

An initial observational finding showed that STTM displayed a similar force-time profile as for the prone thoracic spinal manipulation, characterized by a preload, an impulse, and a resolution phase.\textsuperscript{2}

Repeatability and reliability (within-day and between-day) of the task was assessed regarding the preload and impulse phase. The STTM was found to be reliable for RF magnitude and orientation during repetitive preload and thrust, and also over a 6-month interval. The findings agree with a previous study confirming consistency of thrust manipulation performance applied on a human manikin.\textsuperscript{13}

Preload force application is described as a compression of soft tissue and a joint positioning where the practitioner attempts to reach optimal stiffness until the impulse is applied. The preload phase should represent an important

**Fig 3.** Left: Vector magnitude is displayed on the ground reaction force (platform 1). Right: The RF components (Fx, Fy and Fz) for 3 consecutive preload tasks after 1 single thrust manipulation. RF, reaction force.

**Fig 4.** Average RF at the 3 sessions (left) and overall data comparison (right) for both trained practitioners. RF, reaction force; TP, trained practitioner.
part of the manipulative procedure in the delivery of care, because its modulation suggested different physiological responses. Also, preload force seems to be dependent on the practitioner experience in thoracic and lumbar spine manipulative procedures. Regarding our findings, lower preload data are reported in earlier investigations on prone spinal thrust manipulative procedure, although larger outcomes can be found. Compared with posterior-to-anterior thoracic mobilization, our preload data are comparable to the force magnitude of grade IV mobilization that is considered the grade level before the thrust achievement defined as grade V.

Regular use of manipulative procedure is essential in developing manual skills, and several studies have attested to the significance of practice training to improve accuracy (targeted force level) and consistency in manipulation performances. The results obtained herein confirmed that some preload difference exists between students and TPs but not for all. This small discrepancy may be explained by various individual learning processes and skills acquisition between the fifth-year students during their educational program as previously suggested by Loranger et al. Similarly, Enebo et al demonstrated the benefit of practice training on spinal manipulation performance and competency. However, Descarreaux et al, who have used an instrumented manikin to perform thoracic spine manipulation, did not confirm that preload force differed between students and expert practitioners.

Nevertheless, without defining a targeted force threshold, larger variability among practitioners may occur. On the other hand, our study shows that peak force outcomes for STTM are substantially higher than previous values regarding prone thrust manipulation. Although a wide range of peak force magnitude (from 238 N to 1315 N) is reported in the literature, several authors have proposed threshold peak force values from 300 to 550 N during clinical and experimental applications. The present data are corrected by the weight of the participant’s, trunk but acceleration during the impulse phase and trunk positioning of both the participant and practitioner may still explain some discrepancy in force magnitude for peak force and preload as well. Considering this, it is still reasonable to assume that the present values are comparable to those mentioned above.

Our results support the expectation that during impulse, larger force magnitude is applied relative to preload. Herzog et al have reported a peak force/preload force ratio around 2.5:1 regarding thoracic manipulation in prone. In the present study, this ratio ranged from 1.8:1 to 2.0:1, depending on the trained practitioner.

Interestingly, when normalizing RF magnitude by the TP’s trunk weight (TP1 = 440 N; TP2 = 220 N approximately), relative RF averaged maximally 143% and 273% of trunk weight for preload and thrust, respectively. Moreover, relative RF shows larger values for TP2 compared with TP1 (Fig 5). In other words, the heavier the

### Table 3. Average Zenithal Angle in Degrees (Standard Deviation) During Supine Thoracic Thrust Manipulation for SPs and TPs

<table>
<thead>
<tr>
<th>Zenithal Angle (°)</th>
<th>Preload</th>
<th>Impulse</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP1</td>
<td>10.1 (2.5)</td>
<td>–</td>
</tr>
<tr>
<td>SP2</td>
<td>5.0 (2.7)</td>
<td>–</td>
</tr>
<tr>
<td>TP1</td>
<td>5.2 (2.2)</td>
<td>4.5 (2.2)</td>
</tr>
<tr>
<td>TP2</td>
<td>6.1 (2.5)</td>
<td>5.2 (2.3)</td>
</tr>
</tbody>
</table>

SP, student practitioner; TP, trained practitioner.

Fig 5. Comparison of relative reaction force (RF % by trunk weight) between trained practitioners (TP1 and TP2) for preload and thrust.
practitioner’s trunk, the smaller the relative RF. These results suggest that dynamic features should be further explored to fully understand the HLVA procedure by examining derivative parameters, as it was demonstrated in previous work regarding the cervical spine.35

Noteworthy is that the variability of preload and peak force during STTM was much lower for the 20 years’ experienced practitioner, although the link to experience duration was not analyzed in this study. As suggested by recent work, accuracy of force delivery increases among practitioners with experience and training.36

Another part of the discussion concerns the 3D measurement of RF that allows a more detailed description of spinal manipulative technique including perpendicular and horizontal components (shear forces), as previously described.7 The latter could represent a proper process to fine-tune the application and improve the thrust delivery. As suggested by the authors, this specific characterization of STTM parameters may drive to a better understanding of manipulative techniques in the development of strategies in technical learning and improvement during training (ie, accuracy, comfort, adaptation).

Additionally, the present results demonstrated additional kinetic features of thrust manipulation as the orientation of RF, which is poorly documented during thoracic thrust manipulation. Orientation of force was similar between preload and impulse, confirming that these 2 distinct phases were comparable in achievement.

Limitations

Several limitations have to be considered in the present study. First, students were unfortunately not allowed to perform thrust manipulation on asymptomatic volunteers owing to ethical restrictions, and therefore peak force was not recorded for them. This analysis would have been interesting to assess the ability of fifth-year students to perform thrust manipulation, and to examine their kinetic characteristics to adapt and enhance the teaching-learning process.

Second, the procedure was performed with the participants lying on the ground and not on a medical table as usually applied during clinical practice. Further research should use an instrumented table to better reflect the reality of the manipulative procedure. However, we trust that data obtained are of interest, because the STTM procedure was performed according to rigorous technical steps that should not critically influence the reliability analysis.

Conclusion

The present study is the first that explores biomechanical parameters for supine thoracic thrust manipulation. Task repeatability was assessed by examining reaction vector force for preload, peak force, and zenithal angle, confirming consistency of performance among practitioners. For trained practitioners, the preload was approximately 50% of the peak force, and zenithal angle indicated a vertical orientation of the reaction force during the impulse phase. The present results are of interest for further pedagogical applications on learning manipulative skills to improve safety related to STTM procedures. Further research will explore dynamic parameters (ie, velocity and accelerations) and the potential neurologic effect of such manipulative technique.

Funding Sources and Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): P.M.D., B.B., A.M.
Design (planned the methods to generate the results): B.B., A.M.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): V.F., B.B., P.M.D.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): B.B., A.M.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): B.B., P.M.D.
Literature search (performed the literature search): P.M.D., B.B., A.M.
Writing (responsible for writing a substantive part of the manuscript): P.M.D., B.B.
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): V.F.

Practical Applications

- Kinetic measurement is applicable for supine thoracic thrust manipulation assessment.
- Supine thoracic thrust manipulation is characterized by a high repeatability of RF magnitude and orientation.
- Force feedback including vector force orientation could be beneficial in the spinal manipulation learning process.
REFERENCES


