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Force–time characteristics of hip high velocity, low amplitude manipulation in asymptomatic adults: with and without a drop piece.

Mohsen Kazemi, RN, DC, FRCCSS(C), FCCPOR(C), MSc. PhD[1]
Shivarny Maheswaran, BSc, DC[1]
Grand Choi, DC, FCCC(C)[1]
Alison Yip, DC[1]
Heather Ferns[1]
Glen Harris, DC, FRCCSS(C)[1]
Martha Funabashi, PhD[1]

Objectives: *To describe the force-time characteristics of HVLA hip manipulation (HVLA-HM) with (DP) and without (NDP) a drop-piece.*

Methods: *Twenty asymptomatic participants (22-28 years; 60% female) received 3 whip HVLA-HM (DP) on one hip and 3 whip HVLA-HM (NDP) on the other. Force-time characteristics were collected using Force-Sensing Table Technology (FSTT®) and analyzed descriptively.*

Results: *On average, HVLA-HM (DP) had a 1st peak force initiation of 40N (±19), peak force of 637N (±218), time to 1st peak of 62ms (±26), loading rate of 10763N/s (±5042) and 2nd peak force of 197N (±85). HVLA-HM*

Caractéristiques de la force et du temps de la manipulation de la hanche à haute vélocité et à faible amplitude chez des adultes asymptomatiques: avec et sans planche de vitesse.

Objectifs: *Décrire les caractéristiques de la force et du temps de la manipulation de la hanche à haute vélocité et à faible amplitude (MH-HVLA) avec (PV) et sans (SPV) planche de vitesse.*

Méthodes: *Vingt participants asymptomatiques (22 à 28 ans; 60 % de femmes) ont reçu trois HVLA-MH en coup de fouet (PV) sur une hanche et trois HVLA-MH*en coup de fouet *(SPV) sur l'autre. Les caractéristiques de la force et du temps ont été recueillies à l'aide de la technologie des tables détectant la force (FSTT®) et analysées de manière descriptive.*

Résultats: *En moyenne, la HVLA-MH (PV) avait une première force maximale au départ de 40 N (environ 19), une force maximale de 637 N (environ 218), un temps de première force maximale de 62 ms (environ 26), un taux de charge de 10 763 N/s (environ 5042) et une deuxième force maximale de 197 N (environ 85). La HVLA-MH (SPV) avait une première force maximale au départ de 36 N (environ 23), une force maximale de 567 N (environ*

[1] Canadian Memorial Chiropractic College, Division of Academics, Graduate Studies and Research, Toronto, ON

Corresponding author: Mohsen Kazemi, 6100 Leslie Street, Toronto, ON M2H 3J1
Tel: 416-277-3994
Email: mkazemi@cmcc.ca

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Conflicts of Interest:
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(NDP) had a 1st peak force initiation of 36N (±23), peak force of 567N (±290), time to 1st peak of 63ms (±22), loading rate of 9465N/s (±5966) and 2nd peak force of 197N (±82).

Conclusion: *Forces during these techniques present with slightly higher peak forces and loading rates during HVLA-HM (DP) at the patient-table interface.*

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KEY WORDS: drop-piece, extremity, forces, high velocity low amplitude, hip, manipulation, chiropractic

290), un temps de première force maximale de 63 ms (environ 22), un taux de charge de 9465 N/s (environ 5966) et une deuxième force maximale de 197 N (environ 82).

Conclusion: *Les forces lors de ces techniques présentent des forces maximales et des taux de charge légèrement plus élevés pendant la HVLA-MH (DP) dans le contexte d'un patient sur une planche.*

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MOTS CLÉS : planche de vitesse, extrémité, forces, haute vélocité faible amplitude, hanche, manipulation, chiropratique

Introduction

Chiropractic manipulative therapy (MT) is widely utilized in the management of lower extremity conditions, particularly those involving the hip joint. According to Beliveau *et al*. (2017), 7% of patients seeking chiropractic care had a chief complaint of hip pain.[1] For individuals with hip osteoarthritis, a systematic review found a fair level of limited evidence supporting MT as a short-term intervention when combined with multimodal approaches and exercise therapy.[2] Abbott *et al*. further suggested that manual therapy could lead to significant improvements in patients with hip arthritis,[3] while Hoeksma *et al*. reported that manual therapy was even superior to exercise alone in this population.[4] The benefits of MT are not limited to arthritic conditions, as a recent physiotherapy Clinical Practice Guideline suggests that manual techniques can be considered for pain and joint restriction in the non-arthritic hip as well.[5]

Beyond symptom relief, MT appears to have specific physiological benefits for hip function. Research has shown that drop-piece manipulation can significantly improve pain levels and passive hip abduction, offering a way to improve mobility.[6] High-velocity low-amplitude distraction maneuvers have also been shown to increase the strength of the gluteus maximus, particularly in individuals with knee disorders and hip weakness.[7] In terms of safety, a recent scoping review analyzing adverse events of manual therapy and hip osteoarthritis reported only four cases, all determined to be mild in nature and resolving without treatment,[8] however this area remains under-investigated. Additionally, emerging evidence suggests that manual therapy, such as hip mobilization and movement techniques, may improve balance and muscle activation in patients recovering from stroke.[9] These suggest that MT of the hip may potentially be a beneficial technique for chiropractors to use in their treatments; however, practitioners should consider adverse events and inform patients of such.

Drop tables, boards, or pieces allow specific sections of the table to elevate and release into free fall during a MT and is believed to increase its efficiency (Figure 1).[10,11] Hence, the drop piece MT could be divided into two phases, phase one the force application and free fall, and phase two the counter-reaction when the free fall ends. One theory for the increased efficiency is that the manipulation force and effort by the provider may be reduced.[10] This is due to the drop-piece decreasing the resistance of both the table and the patient in phase one.[10] Another potential explanation is that the force of the manipulation is enhanced by the counter-reactive force generated across the joint when manipulation thrusts are maintained through the impact of the drop-piece in phase two.[10,12] Both proposed explanations are based on Newton's first law, which states that a body is in equilibrium if no force is acting upon it. If at rest, it remains so; if in motion, it persists in motion unless acted upon by a force. When drop pieces are used, it is believed that the thrust executed by the practitioner imparts motion to the targeted joint

which was at rest, the fall of the drop piece may reduce the table resistance resulting in larger motion of the body part. This joint remains in motion based on Newton's fist law until the end of the drop which stops the motion.[13]

Bergmann and Davis[13] outline the basic procedure for using a drop-piece as follows: First, the targeted joint is positioned over the drop section. Then, the drop-piece is set, and its "tension" (in this context, referring to the amount of force required to drop the drop-piece) is checked. The tension should be enough to support the patient's weight without dropping, but light enough so that only minimal force is needed to overcome the resistance (Figure 1).[14] Finally, contacts are established over the structure to receive the thrust, and a thrust is generated to make the section drop. This procedure is repeated for a total of three times.[13]

Drop-piece manipulation is a common chiropractic technique, accounting for approximately 6.3% of total chiropractic interventions in Ontario.[15] Clijsters *et al.* found 10% of chiropractors used drop technique as the first choice to treat lumbar facet syndrome, while 18% used drop technique as the first choice for sacroiliac dysfunction treatment.[16] While the technique is widely used, there is a lack of research investigating its force-time characteristics during high-velocity, low-amplitude (HVLA) manipulations.[17] Previous studies have explored force characteristics during spinal manipulations [18-20] and hip mobilizations,[21] but no study has quantified these characteristics for HVLA hip manipulations (HVLA-HM) performed with and without a drop-piece.

As such, our study seeks to shed some light on this unexplored and yet important area. The study addresses the needs expressed in the literature to improve our understanding of HVLA-HM in managing lower extremity conditions.[2] By describing the force-time characteristics of HVLA-HM with and without drop-pieces, this study aims to provide an initial understanding of the forces during this intervention.

Methods

Study design

This descriptive observational cross-sectional study quantified the force-time characteristics at the participant-table interface during HVLA-HM with and without the use of a drop-piece. The study was conducted in July 2024 at the Force-Sensing Table Technology (FSTT®) lab at Canadian Memorial Chiropractic College (CMCC) in Toronto, Canada. Ethical approval was obtained from the Research Ethics Board (REB) at CMCC (approval #2404B01), and all participants provided informed consent before their involvement.

Participants

This was the first study investigating the force-time characteristics of HVLA manipulations of the hip with and without drop-pieces. Given that this was a descriptive observational study, no inferential statistics were conducted. The study recruited 20 participants through email notifications, community social media pages, and campus posters. Participation was voluntary and could be withdrawn at any time without penalty or academic consequences. Recruitment and informed consent were conducted by non-instructor staff. Participants received a $10 gift card for their participation. Participants were asymptomatic adult chiropractic students at CMCC. Inclusion criteria required participants to be 18 years or older with no history of hip symptoms or injuries, including pain in the groin, lateral hip, gluteal region, or knee. Exclusion criteria included ongoing or recent low back or hip pain, prior hip, knee, ankle, or back surgery, hip adjustments within the previous week, or ongoing knee or ankle injuries.

Intervention

High-velocity, low-amplitude hip manipulation

HVLA-HM with drop-piece: participant was supine on the FSTT® table with the drop-piece (Figures 1-2) tension set by determining the amount necessary for the drop-piece to collapse under the participant's body weight and then increased by a ½ rotation of tension knob clockwise (Figure 1). The chiropractor took the participant's targeted leg with one hand, contacting the posterior knee, while the other hand contacted the ankle with approximately 90 degrees of hip flexion, 20-30 degrees of hip abduction and 15-20 degrees of external rotation. The chiropractor initiated a posterior-caudal thrust ending in approximately 15-20 degrees of hip extension, 20-30 degrees of hip abduction and 15-20 degrees of hip external rotation similar to a whip motion, which at the end point transferred the force into the table and released the drop-piece (Figures 3-4). The chiropractor repeated the procedure 3 times.

HVLA-HM without drop-piece: Similar to the previous technique, however without the drop-piece. Specific-

ally, the participant was supine on the FSTT® table, the chiropractor took the participant's targeted leg with one hand, contacting the posterior knee, while the other hand contacted the ankle with approximately 90 degrees of hip flexion, 20-30 degrees of hip abduction and 15-20 degrees of external rotation. The doctor initiated a posterior-caudal long-axis thrust ending in approximately 15-20 degrees of hip extension, 20-30 degrees of hip abduction and 15-20 degrees of hip external rotation similar to a whip motion, which at the end point transferred the force into the table (Figures 3-4). The chiropractor repeated the procedure 3 times.

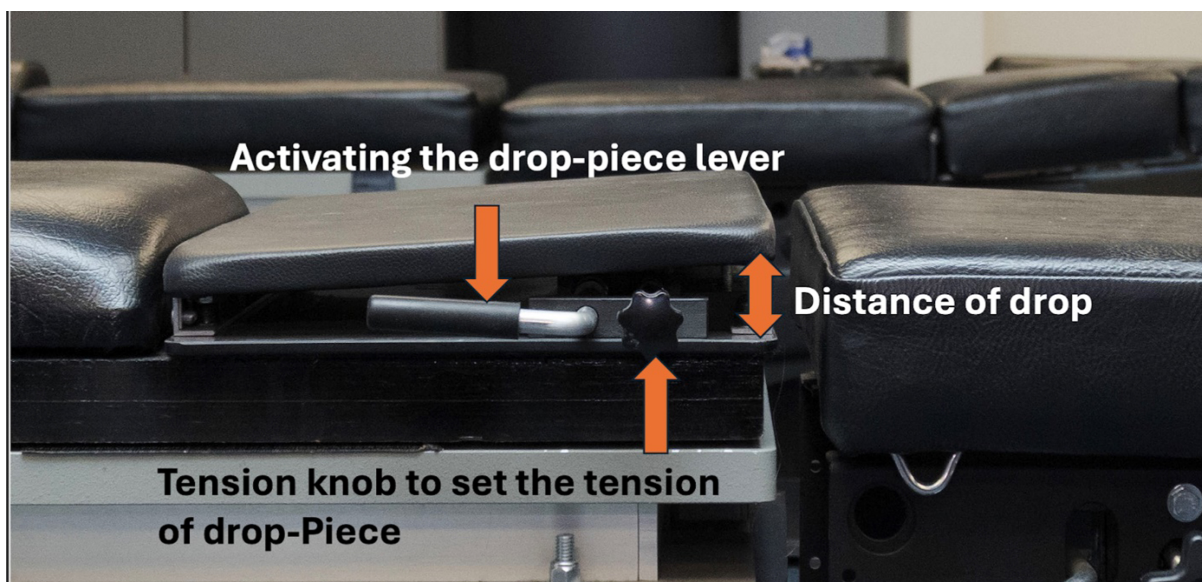

Figure 1.
Drop-piece components

Figure 2.
The FSTT® system, equipped with a modified Elite Stationary treatment table with drop-pieces and an embedded AMTI force plate.

Figure 3.
High-velocity, low-amplitude hip manipulation (HVLA-HM) starting point.

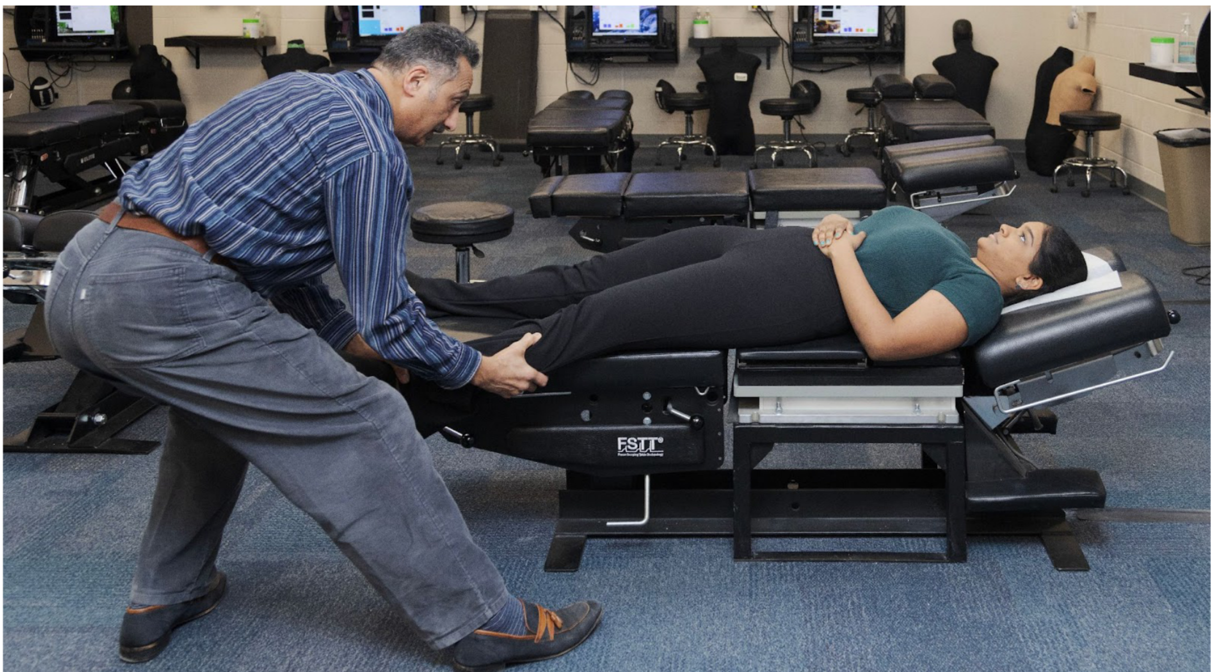

Figure 4.
High-velocity, low-amplitude hip manipulation (HVLA-HM) endpoint.

Instrumentation

Force-time data were collected for each HVLA-HM trial using the Force Sensing Table Technology (FSTT®, Canadian Memorial Chiropractic College, Toronto, ON, Canada). The FSTT® consisted of a modified Elite Stationary treatment table (Elite Chiropractic Tables, Jarvis, Ontario, Canada) with an embedded 6-degree-of-freedom force plate (AMTI Inc., Watertown, MA) with a 2KHz sampling rate. This device measured the three-dimensional reaction forces and moments at the interface between the table and the participant during the HVLA-HM. The FSTT® table was custom outfitted with a ChiroLux AirDrop drop-piece (Spokane, WA), which replaced the standard thoracic cushion. The raw input was analyzed automatically using FSTT® software. The raw force–time data was processed using a 20 Hz low-pass, 2nd order Butterworth filter to remove noise artifacts. The mean value from a one-second recording, prior to each trial recording, was designated as the zero and subtracted from the subsequent trial recording. This zero-trial adjustment accounted for each subject's body weight, ensuring that only the net forces resulting from the adjustment were analyzed. The drop-piece tension was checked before every subject and before each trial. The FSTT® has been demonstrated to be a valid tool for measuring force-time parameters of manual therapies.[22, 23] The following force-time characteristics were recorded: force initiation, first and second impulse peak force, time to first peak force, and loading rate of first peak force. Force initiation was the force at the moment where a measurable increase in force begins to occur, indicating the start of the thrust. First impulse peak force was the maximum force reached during the thrust. Secondary impulse peak force was a secondary peak in the force-time curve observed after the initial thrust. Time to first peak was measured as the time interval between force initiation and first impulse peak force. Loading rate of first peak force was calculated as the rate of force increase from force initiation to first peak force.

Study protocol

Each participant attended a single 30-minute session. During the session, participants completed a short survey regarding their demographic characteristics and received three HVLA-HM with a drop-piece on one leg and three without a drop-piece on the opposite leg. The sequence of manipulations (with and without drop-piece) and the hip to be manipulated were randomized to minimize order effects and potential biases related to leg dominance. The randomization and envelope preparation were completed by an investigator (SM) using the online tool "Research Randomizer". Participants selected an opaque envelope containing this information, and one investigator (SM/HF/AY) recorded the participant's assigned number on the envelope. All HVLA-HM were performed by experienced chiropractors (MK/GC) using the FSTT® to measure and record force-time characteristics. No practice thrusts were performed before data collection began. There were no rests between thrusts.

Data processing

Force-time data were exported from the FSTT® system with custom-made software using the Matlab platform (Mathworks, Natick, MA, USA). For each trial, the software automatically identified force initiation and peak points, which were then verified manually by the investigators (SM/HF/AY). Key thrust landmarks were identified using the custom-built FSTT® software. The software determines force initiation when the loading rate surpasses a defined threshold value. This threshold was established following an analysis of a diverse range of thrust examples and was found to most accurately represent force initiation in the majority of trials. In instances where the software misidentified landmarks or secondary peaks were present, the correct landmarks were easily verified through visual inspection of the filtered data. Raw force-time data were processed using a 20 Hz low-pass, second-order Butterworth filter. The loading rate was calculated as the average slope from the point of force initiation to the peak force value in the force-time plotting of the data.

Data analysis

Descriptive statistics were calculated for each outcome variable, including mean/median, standard deviation, and 95% confidence intervals (95% CI = Mean ± (T.INV.2T(0.05, n-1) / 2) * (Standard_Deviation / SQRT(n))) using the Microsoft Excel program version 2509. Outcome variables were calculated per thrust ($n = 60$ for DP and $n = 57$ for NDP). Trials with instrumentation or software errors were excluded from analysis.

HVLA-HM does not follow the typical force-time pat-

terns of posterior-to-anterior spinal manipulation. [20,23,24] Therefore, slow-motion videography (Fastec TS5, Fastec Imaging Corp. USA) was used to match force-time graphs with the corresponding phases of the manipulation with a custom-made software written in Matlab. The camera captured images at 500 FPS (frames per second). Slow-motion images were synchronized with FSTT® data by using a custom-made software written in Matlab. A custom synchronization device was developed to align the high-speed camera with the FSTT® force data. When activated by a trigger switch, an LED illuminated within the camera's view while a simultaneous TTL pulse was sent to the data acquisition unit recording the force data. The LED flash and TTL pulse served as a common event for synchronization between the force and video data. The FSTT® force data (2000 Hz) were subsequently downsampled to match the high-speed camera's frame rate (500 Hz). This allowed precise identification of force initiation, first and second peak force, time to first peak force, and loading rate.

The force components Fx, Fy, and Fz represent the forces in the medial-lateral (x-axis), caudad-cephalad (y-axis), and anterior-posterior (z-axis) axes relative to participants. Fres, the magnitude of the resultant force, was calculated (Equation 1) and chosen as the primary variable for analysis, since it provides a comprehensive measure of the overall force applied. Primary outcome = Fres; component forces are secondary descriptors provided in Tables 3–6.

Equation 1.

$$F_{res} = \sqrt{\left(F_x^2 + F_y^2 + F_z^2\right)}$$

Results

Participants

The study recruited 20 participants, and no participants were excluded. However, one trial (3 HVLA-HM (NDP) thrusts of the left leg, from one participant) was removed from analysis due to an instrument error in recording the force-time profile. Final analyzable thrusts include 60 DP and 57 NDP. No other exclusions were necessary. Participant demographic data are summarized in Table 1.

Overview of findings

Two peak forces were observed during HVLA-HM with and without a drop-piece. The average findings are shown in Table 2, for drop-piece and no drop-piece HVLA-HM.

Table 1.
Participant demographics

Total Participants	Female: Male Ratio	Mean Age (years) (±SD)	Mean Height (cm) (±SD)	Mean Weight (kg) (±SD)	Average BMI (kg/m²) (±SD)
20	3:2	25 (±1.65)	171.35 (±8.93)	75.85 (±16.58)	25.66 (±4.55)

Table 2.
Average parameters for drop-piece and no drop-piece HVLA-HM.

Parameter	HVLA-HM with Drop-Piece Mean (±SD) (95% CI)	HVLA-HM without Drop-Piece Mean (±SD) (95% CI)
First Peak Force Initiation (N)	39.55 (±19.40) (29.54, 48.67)	35.96 (±22.58) (30.25, 41.68)
First Peak Force (N)	637.06 (±218.47) (542.98, 798.25)	567.16 (±290.69) (493.61, 640.70)
Second Peak Force (N)	197.08 (±85.47) (173.75, 220.41)	197.37 (±81.74) (176.51, 218.22)
Time to First Peak Force (ms)	62.34 (±25.55) (55.74, 68.94)	62.82 (±21.88) (57.29, 68.36)
Loading Rate (N/s)	10,763.38 (±5,042.31) (9,498.18, 12,028.58)	9,464.72 (±5,965.50) (7,955.45, 10,973.98)

The force-time graphs displayed in figure 5 provide a visualization of the forces measured at the participant-table interface during HVLA-HM with (A) and without (B) a drop-piece. The peak force and the onset of force application were identified from the resultant force–time curve, and their corresponding locations were superimposed onto the respective Fx, Fy, and Fz component plots.

Fres consistently showed two peaks in both conditions (Fig. 5). Interpretation of these peaks appears in the Discussion. Side specific details (left/right) appear in Tables 3–6; pooled results are presented as primary. Given mild skew, both mean±SD and median (IQR) are reported; mean±SD are primary.

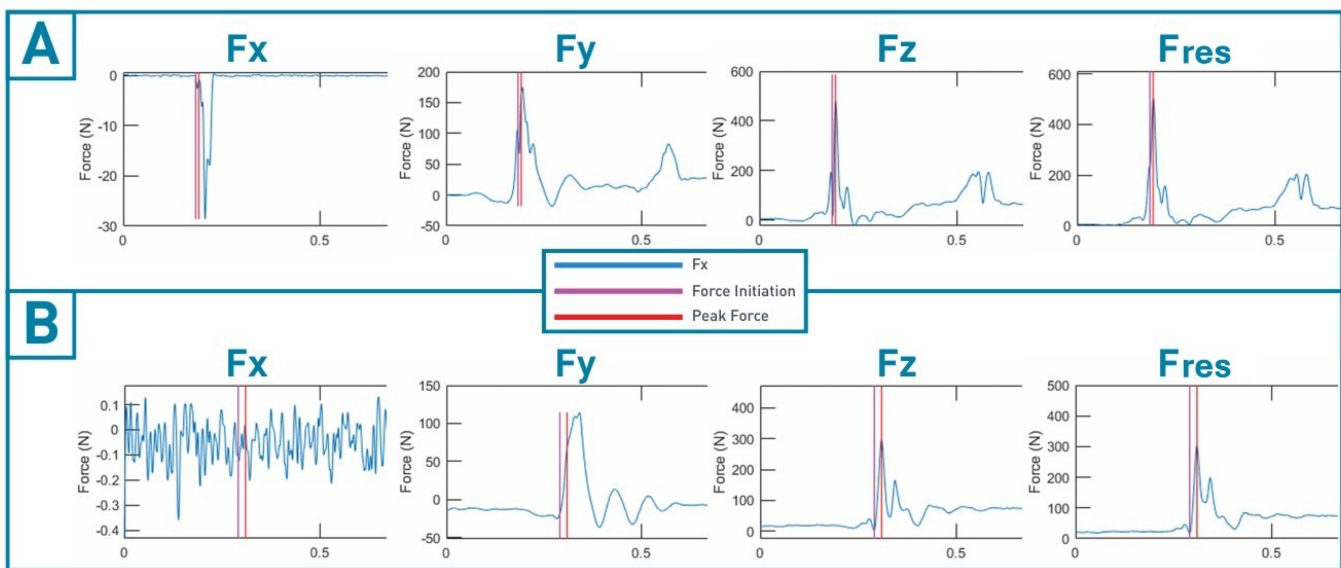

Figure 5.
Force-time graph for HVLA-HM with drop-piece(a) and without drop-piece (b) Fx: forces in the medial-lateral (x-axis), Fy: caudad-cephalad (y-axis), Fz: anterior-posterior (z-axis) axes relative to participants. Fres: the magnitude of the resultant force. Please note the force scales are different for Fx and Fy from the scale for Fz and Fres.

Table 3.
Forces during 1st peak for HVLA-HM with and without drop-piece

Drop & Leg	Mean Fx (N) (SD) (95% CI)	Median Fx (N)	Mean Fy (N) (SD) (95% CI)	Median Fy (N)	Mean Fz (N) (SD) (95% CI)	Median Fz (N)	Mean Fres (N) (SD) (95% CI)	Median Fres (N)
Drop Left	-1.77 (±3.19) (-2.77, -0.78)	-0.42	49.43 (±76.84) (25.48, 73.37)	61.81	624.85 (±306.57) (529.31, 720.38)	645.01	680.74 (±232.01) (608.44, 753.04)	673.67
Drop Right	-12.20 (±21.12) (-22.71, -1.70)	-3.72	95.44 (±80.31) (55.50, 135.37)	122.57	444.77 (±264.04) (313.46, 576.08)	546.03	535.16 (±141.81) (464.64, 605.68)	566.24
Drop Left & Right	-4.90 (±12.60) (-5.15, -0.83)	-0.80	63.23 (±80.08) (-20.98, 123.56)	65.68	570.83 (±303.85) (471.63, 737.48)	594.85	637.06 (±218.47) (542.98, 798.25)	619.72
No Drop Left	0.01 (±0.07) (-0.03, 0.04)	0.02	113.32 (±46.56) (89.38, 137.26)	100.46	417.09 (±151.20) (339.35, 494.83)	399.93	436.58 (±140.36) (364.41, 508.74)	429.63
No Drop Right	-40.03 (±52.69) (-56.45, -23.61)	-14.81	84.88 (±72.57) (62.26, 107.49)	85.27	605.99 (±323.38) (505.22, 706.77)	557.72	620.02 (±319.25) (520.53, 719.50)	570.13

Drop & Leg	Mean Fx (N) (SD) (95% CI)	Median Fx (N)	Mean Fy (N) (SD) (95% CI)	Median Fy (N)	Mean Fz (N) (SD) (95% CI)	Median Fz (N)	Mean Fres (N) (SD) (95% CI)	Median Fres (N)
No Drop Left & Right	-28.49 (±47.92) (-40.62, -16.37)	-0.18	93.07 (±67.00) (76.12, 110.02)	90.16	551.56 (±296.10) (476.65, 626.48)	460.75	567.16 (±290.69) (493.61, 640.70)	479.48

Fx = Forces in the medial-lateral direction. In the context of a subject positioned supine on the table, a positive force value denotes a vector directed toward the subject's right side, whereas a negative value indicates a vector directed toward the left side.
Fy = Forces in the caudad-cephalad direction. A positive force value corresponds to a vector directed in the caudal direction, whereas a negative value denotes a force oriented cephalad.
Fz = Forces in the anterior-posterior direction. A positive force value denotes a vector going into the table.
Fres = Resultant force
Drop = With drop-piece
No Drop = Without drop-piece
SD = Standard Deviation
95% CI = 95% Confidence Interval

Table 4.
Forces during 2nd peak for HVLA-HM with and without drop-piece

Drop & Leg	Mean Fx (N) (SD) (95% CI)	Median Fx (N)	Mean Fy (N) (SD) (95% CI)	Median Fy (N)	Mean Fz (N) (SD) (95% CI)	Median Fz (N)	Mean Fres (N) (SD) (95% CI)	Median Fres (N)
Drop Left	0.05 (±0.09) (0.02, 0.07)	0.05	123.10 (±57.35) (104.50, 141.69)	117.84	135.39 (±135.54) (91.46, 179.33)	116.12	211.44 (±95.77) (180.40, 242.49)	193.49
Drop Right	-18.14 (±19.33) (-28.85, -7.44)	-10.24	76.47 (±53.65) (46.75, 106.18)	91.10	51.26 (±124.38) (-17.62, 120.15)	110.08	159.75 (±26.24) (145.22, 174.28)	157.93
Drop Left & Right	-5.01 (±12.90) (–9.28, 9.49)	0.00	110.14 (±59.69) (94.37, 125.92)	103.90	112.03 (±303.85) (75.89, 148.17)	112.67	197.08 (±85.47) (173.75, 220.41)	163.53
No Drop Left	0.02 (±0.08) (-0.02, 0.06)	0.00	109.72 (±63.86) (76.89, 142.56)	101.35	39.60 (±118.68) (-21.42, 100.62)	77.79	165.52 (±57.56) (135.93, 195.11)	165.57
No Drop Right	-37.19 (±32.05) (-47.31, -27.08)	-31.00	143.00 (±47.43) (128.03, 157.97)	141.56	125.03 (±107.52) (91.09, 158.96)	107.45	210.57 (±87.09) (183.91, 237.23)	188.19
No Drop Left & Right	-26.29 (±31.82) (-34.40, -18.17)	-12.23	133.24 (±54.37) (119.37, 147.12)	129.22	99.99 (±116.64) (70.23, 129.75)	106.44	197.37 (±81.74) (176.51, 218.22)	178.13

Fx = Forces in the medial-lateral direction. In the context of a subject positioned supine on the table, a positive force value denotes a vector directed toward the subject's right side, whereas a negative value indicates a vector directed toward the left side.
Fy = Forces in the caudad-cephalad direction. A positive force value corresponds to a vector directed in the caudal direction, whereas a negative value denotes a force oriented cephalad.
Fz = Forces in the anterior-posterior direction. A positive force value denotes a vector going into the table.
Fres = Resultant force
Drop = With drop-piece
No Drop = Without drop-piece
SD = Standard Deviation
95% CI = 95% Confidence Interval

Forces during force initiation, time to first peak, and load rate for HVLA-HM with and without drop-piece are recorded in Table 5 and 6 respectively.

Table 5.
Forces during force initiation for HVLA-HM with and without drop-piece

Drop & Leg	Mean Fx (N) (SD) (95% CI)	Median Fx (N)	Mean Fy (N) (SD) (95% CI)	Median Fy (N)	Mean Fz (N) (SD) (95% CI)	Median Fz (N)	Mean Fres (N) (SD) (95% CI)	Median Fres (N)
Drop Left	-0.28 (±2.10) (-0.93, 0.38)	0.06	-8.45 (±34.01) (-19.05, 2.15)	-1.52	-11.26 (±26.11) (-19.39, -3.12)	-10.36	40.90 (±20.47) (34.52, 47.28)	41.87
Drop Right	0.07 (±0.55) (-0.20, 0.34)	0.05	11.02 (±17.80) (2.17, 19.87)	15.17	-9.09 (±30.01) (-24.02, 5.84)	-9.13	36.42 (±16.74) (28.100, 44.75)	35.42
Drop Left & Right	-0.17 (±1.78) (-0.59, -0.00)	0.06	-2.61 (±31.24) (-10.68, 5.46)	3.76	-10.61 (±27.10) (-18.56, -6.43)	-9.66	39.55 (±19.40) (29.54, 48.67)	38.54
No Drop Left	0.00 (±0.08) (-0.04, 0.04)	0.03	3.05 (±26.85) (-10.75, 16.86)	1.71	-13.19 (±25.81) (-26.47, 0.08)	-14.21	34.97 (±19.20) (25.10, 44.84)	33.39
No Drop Right	0.74 (±1.22) (0.36, 1.12)	0.17	-9.24 (±27.66) (-17.86, -0.62)	-2.12	-24.36 (±27.69) (-32.98, -15.73)	-20.46	36.36 (±24.02) (28.88, 43.85)	32.71
No Drop Left & Right	0.53 (±1.08) (0.26, 0.80)	0.08	-5.70 (±27.77) (-12.72, 1.33)	-1.56	-21.14 (±27.42) (-28.08, -14.20)	-19.91	35.96 (±22.58) (30.25, 41.68)	32.95

Fx = Forces in the medial-lateral direction. In the context of a subject positioned supine on the table, a positive force value denotes a vector directed toward the subject's right side, whereas a negative value indicates a vector directed toward the left side.
Fy = Forces in the caudad-cephalad direction. A positive force value corresponds to a vector directed in the caudal direction, whereas a negative value denotes a force oriented cephalad.
Fz = Forces in the anterior-posterior direction. A positive force value denotes a vector going into the table.
Fres = Resultant force
Drop = With drop-piece
No Drop = Without drop-piece
SD = Standard Deviation
95% CI = 95% Confidence Interval

A paired plot of per participant first peak Fres (DP vs NDP) is provided in Figure 6.

Discussion

This study is the first to investigate the force-time characteristics of HVLA-HM with and without a drop-piece. The findings of this study build upon previous research on hip mobilization techniques and spinal manipulation force-time characteristics.

Prior research on hip mobilizations found that forces averaging 68.6N (±2.9) were effective in improving range of motion in hip osteoarthritis patients.[21] In contrast, our study examined force characteristics of HVLA-HM in asymptomatic participants and identified the mean first peak force at 637N (±218) with the drop-piece and 567N (±290) without the drop-piece. This is possibly a result of using HVLA instead of mobilization and the method of measurement they used which only recorded perpendicular forces. Because measurements were taken at the table–patient interface, inferences are limited to that interface and do not quantify joint or tissue forces.

Previous studies investigating spinal manipulation (cervical, thoracic and lumbosacral regions) force-time characteristics without drop-piece reported peak forces ranging from 17N to 1,213N and time-to-peak thrust force ranging from 12ms to 938ms.[18] Our results align within this range but highlight the distinct force dynamics of hip manipulations compared to spinal manipulations.

A unique finding of this study was the identification of two peak forces during HVLA-HM, a characteristic not reported in previous spinal manipulation studies without drop-piece tables. See Fig. 5A (DP) and Fig. 5B (NDP)

Table 6.
Time to first peak and load rate for HVLA-HM with and without drop-piece

Drop & Leg	Mean Time to First Peak (ms) (SD) (95% CI)	Median Time to First Peak (ms)	Mean Load Rate (N/s) (SD) (95% CI)	Median Load Rate (N/s)
Drop Left	56.12 (±16.44) (51.00, 61.24)	50.75	11,969.85 (±4,804.20) (10,472.76, 13,466.95)	10,304.17
Drop Right	76.86 (±35.98) (58.97, 94.76)	61.5	7,948.27 (±4,537.38) (5,691.88, 10,204.65)	6,218.98
Drop Left & Right	62.34 (±25.55) (55.74, 68.94)	52.5	10,763.38 (±5,042.31) (9,498.18, 12,028.58)	9,647.84
No Drop Left	61.5 (±12.81) (54.91, 68.09)	58.00	6,866.05 (±3,051.36) (5,297.18, 8,434.91)	6,761.01
No Drop Right	63.36 (±24.74) (55.65, 71.07)	56.75	10,516.56 (±6,540.33) (8,478.45, 12,554.67)	9,690.12
No Drop Left & Right	62.82 (±21.88) (57.29, 68.36)	57.00	9,464.72 (±5,965.50) (7,955.45, 10,973.98)	7,640.63

Fx = Forces in the medial-lateral direction. In the context of a subject positioned supine on the table, a positive force value denotes a vector directed toward the subject's right side, whereas a negative value indicates a vector directed toward the left side.
Fy = Forces in the caudad-cephalad direction. A positive force value corresponds to a vector directed in the caudal direction, whereas a negative value denotes a force oriented cephalad.
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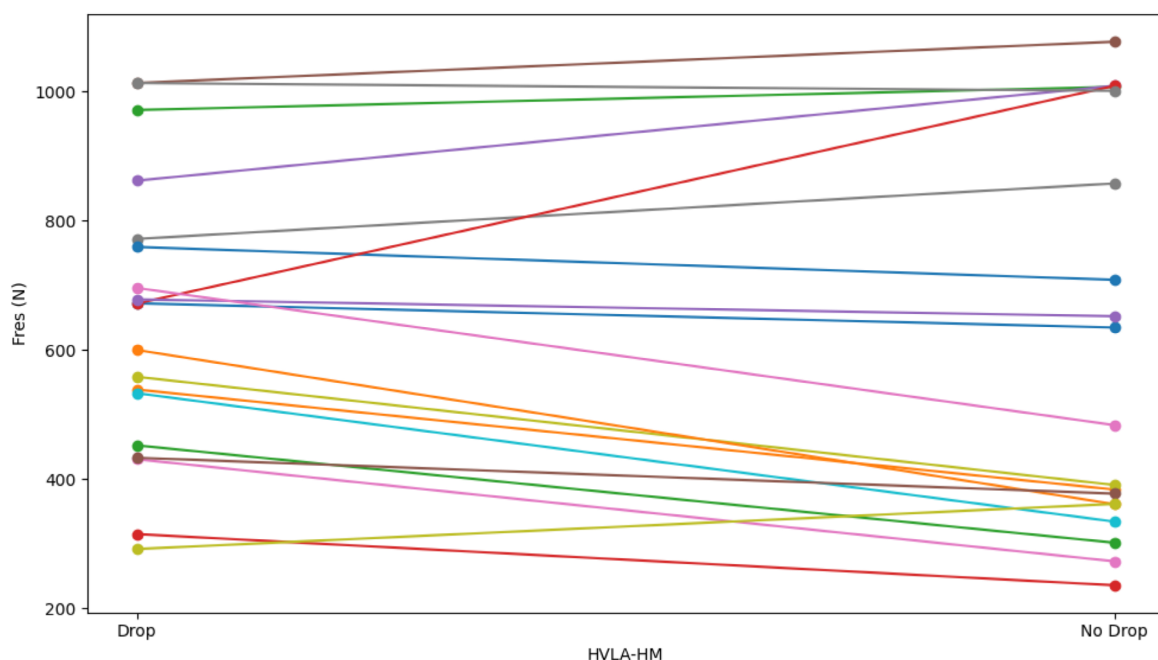

Figure 6.
Paired plot of per participant first peak Fres (DP vs NDP). One participant excluded from plot due to instrument error of NDP trial.

Fres panels for first and second peak landmarks. DeVocht *et al*.[17] identified a similar dual-peak force-time profile in toggle-recoil cervical spine manipulation which utilizes drop-piece similar to the drop-piece used in our study. They proposed that the first peak represents the force required to release the drop mechanism, while the second peak is due to continued practitioner force application after the table has completed its drop. The presence of a dual-peak in our study may differ from what was observed and suggested by DeVocht *et al*.[17] since they were observed in both drop-piece and non-drop-piece manipulations at very similar force (197N). This is most likely related to the whip action manipulation used in our study inducing body bouncing causing the similar second peak in both drop-piece and non-drop-piece manipulations. In contrast, the forces in toggle recoil manipulation of cervical spine were in sagittal superior to inferior directions. The drop-piece technique resulted in a higher first peak force and a more rapid time-to-peak force compared to the non-drop technique, likely due to the mechanical advantage of using the participant's mass provided by the drop mechanism. The second peak force was similar in both drop-piece and non-drop-piece techniques. While slow motion video suggests Peak 1 demonstrating the thrust of manipulation and Peak 2, post thrust body motion, this interpretation is tentative given the measurement location. Differences in force-time characteristics have been described for different spinal manipulation techniques.[20,23,24] Therefore, given that the HVLA-HM used in our study differs from the cervical manipulation used in Devocht et al.[17] it was expected that forces measured in our study would also differ from previous studies using drop-piece with different techniques.

Similar to our study that did not identify a preload phase during the HVLA-HM, a study on cervical manipulation methods also found that the toggle board technique did not have a detectable preload phase.[25] This is in contrast to manipulations applied to the spine, where preload is usually applied to remove the skin slack before the thrust application, whereas the toggle board adjustments allowed the thrust application without a preload phase. This feature may enable a rapid force delivery and a shorter thrust duration.

Some authors theorized that the higher loading rates achieved with the drop-piece technique could potentially enhance therapeutic outcomes by delivering a more efficient force transmission to the targeted joint.[26, 27] However, the clinical significance of the observed higher mean first peak forces and loading rates with the drop piece at the table–patient interface is unknown and requires further investigation.

Further research is needed to investigate the clinical outcomes associated with these force-time differences and to explore whether these mechanical advantages translate to improved patient outcomes.

This study has several limitations that should be considered when interpreting the findings. The force data was collected at the patient-table interface, which does not capture forces within the hip joint or surrounding soft tissue or the forces directly applied by the chiropractors. The nature of the intervention prevented blinding of both the participants and practitioners, which may introduce performance bias. Manipulations were performed by two experienced chiropractors, which does not account for the variation in technique seen across clinicians. Variability of tables constructs, drop piece settings and operations were not accounted for in our study. Adverse effects of the manipulations were not investigated. Due to the observational design of the study, no statistical significance or causation conclusions can be drawn. The use of asymptomatic participants limits the generalizability to clinical populations, as people with hip pain may demonstrate altered force responses due to muscle guarding or joint pathology. Given the asymptomatic sample, two operators, potential table variability, and the descriptive design, conclusions are intentionally non inferential.

Conclusion

This study provides novel insights into the force-time characteristics of HVLA-HM with and without a drop-piece. The use of a drop-piece resulted in higher peak forces, and increased loading rates. These findings may inform the training of chiropractic techniques. Future studies should pair force–time metrics with patient reported outcomes and safety monitoring and examine operator technique and drop piece tension as experimental factors.

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