Unilateral and Multiple Cavitation Sounds During Lumbosacral Spinal Manipulation

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Abstract

Objective: The purpose of this study was to determine from which side of the spine the popping sound (PS) emanates during side-lying, rotatory high-velocity low-amplitude (HVLA) thrust manipulation directed to the L5-S1 articulation using a time-frequency analysis. Secondary aims were to calculate the average number of PSs, the duration of lumbar thrust manipulation, and the duration of a single PS.

Methods: Thirty-four asymptomatic participants received 2 lumbar HVLA thrust manipulations targeting the right and left L5-S1 articulations. Two high sampling rate accelerometers were secured bilaterally 25 mm lateral to the midline of the L5-S1 interspace. For each manipulation, 2 audio signals were extracted and singularly processed via spectrogram calculation to obtain the release of energy over time on each side of the lumbosacral junction.

Results: During 60 HVLA thrust manipulations, it was measured a total of 320 PSs. Of those PSs, 176 occurred ipsilateral and 144 occurred contralateral to the targeted L5-S1 articulation; that is, the PS was no more likely to occur on the upside than the downside facet after right or left rotatory L5-S1 HVLA thrust manipulation. Moreover, PSs occurring on both sides at the same time were detected very rarely (ie, 2% of cases) with the lumbar HVLA thrust manipulations. The mean number of audible PSs per lumbosacral HVLA thrust manipulation was 5.27 (range 2-9). The mean duration of a single manipulation was 139.13 milliseconds (95% confidence interval: 5.61-493.79), and the mean duration of a single PS was 2.69 milliseconds (95% confidence interval: 0.95-4.59).

Conclusion: Based on our findings, spinal manipulative therapy practitioners should expect multiple PSs that most often occur on the upside or the downside facet articulations when performing HVLA thrust manipulation to the lumbosacral junction (ie, L5-S1). However, whether the multiple PSs found in this study emanated from the same joint or adjacent ipsilateral or contralateral facet joints remains unknown. A single model may not necessarily be able to explain all of the audible sounds during HVLA thrust manipulation. (J Manipulative Physiol Ther 2019;42:12-22)

Key Indexing Terms: *Manipulation; Spinal; Lumbosacral Region*

Introduction

The popping sound (PS) or audible cracking consists of a high-frequency vibration that should be expected as a desired effect by the delivery of a high-velocity thrust (HVLA) applied from an external force that creates motion at a joint level.

The PS is considered one of the main features to define a HVLA thrust manipulation[1] and to achieve an effective delivery of this technique.[2-8] That is, many clinicians and research teams still repeat the HVLA thrust manipulation if the PSs were not emanated.[2,6,7,9-14] However, the PS phenomenology is still not fully understood.

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Paper submitted December 24, 2017; in revised form June 29, 2018; accepted August 31, 2018.
0161-4754

https://doi.org/10.1016/j.jmpt.2018.08.002

Since the early 1900s, considerable attention has been given to which anatomical structures are involved and what the exact mechanisms are behind the genesis of the PS.[15] That is, gas bubble collapse[16] into the joints driven by the "cavitation" physic phenomenon has been traditionally accepted as the main mechanism.[1,3,16-20] However, recently and according to Roston and Haines,[21] Kawchuk et al[15] observed that joint PS is associated with a cavity inception within the metacarpal-phalangeal (MCP) joint using rapid cine magnetic resonance images. This is the first in vivo macroscopic demonstration of the tribonucleation physic process as a new theoretical model of the mechanism of the PS phenomenon. Tribonucleation occurs when 2 opposed joint surfaces separated by a film solution are rapidly separated by a distractive force that overcomes the viscous attraction. More recently, Chandran Suja and Barakat,[22] using a complex mathematical model based on a microphone registration away from the MCP joint, found that the PS was not related to the cavity inception (ie, tribonucleation) but results from the intra-articular pressure drop leading to cavitation bubble release in the synovial fluid. That is, the results of this study confirm the experimental first observation that Unsworth et al found in 1971.[16] However, the persistence of a cavity after the sound production is congruent with the observation made by Kawchuk et al.[15]

These findings cannot be generalized because they were observed only on MCP joints from a few participants.[15,16,21,22] Moreover, the anatomical differences between the MCP and the zygapophyseal joints (ZJs) also has to be considered.

That is, Cascioli et al[23] did not find any gas genesis into the cervical joint space nor increased joint gapping (ie, joint width) using computed tomography scans immediately after a HVLA thrust manipulation delivery on the cervical region. However, using magnetic resonance imaging to measure the central anterior-posterior joint space, Cramer et al found the greatest gapping of the lumbar ZJ following a single session of spinal manipulative therapy in participants experiencing low back pain compared to those who received side-posture positioning (ie, no-thrust manipulation).[24] Moreover, in a previous study, Cramer observed a direct relation between the popping sound and the gapping phenomena but not how much the joint gapped.[25] Notably, Kawchuk et al[15] found a void within the joint that persists after the sound production that could explain the ZJ gapping after HVLA thrust manipulation observed by Cramer et al.[24,25]

More recently, another research group tried to analyze the PS phenomenon using sound wave signals processed by a time-frequency analysis.[8,26] The authors observed that the sound was composed of single and multiple energy releases (ie, single versus multi-peak sounds). Furthermore, they identified high and low sounds and sounds of multiple frequencies. These multiple feature findings of the PS suggest more mechanisms in addition to the tribonucleation or cavitation underlying the PS origin.

Sound recording (eg, microphones and accelerometers) also was extensively used as an indirect measure to better understand the PS phenomenon. Woods and West compared the PS emanating from different spine regions (ie, temporomandibular, cervical, thoracic, and lumbar spine).[27] The authors ran a frequency analysis of the sound signals using a fast Fourier transform observing multiple frequency features.

Reggars in a critical review was the first to underline the need for a discriminative spectrographic analysis to better study the PS at the ZJ level[27] and subsequently validated the reliability and accuracy of multiple surface mounted microphones as an acquisition system to detect the PS of the third MCP joint.[18]

Then, a further step was taken by Reggars and Pollard,[28] which introduced the spectrographic analysis of the recorded signal from skin-mounted microphones during HVLA thrust manipulation of the cervical spine. In this study, the authors observed the side and number of PSs emanated during a HVLA thrust manipulation delivery, leading to questioning the expected real target specificity. Again, the authors concluded that it was not possible to explain this phenomenon based on a single mechanism because the observation of heterogeneous frequency peak in the same recording suggested that validated technology and acquisition methodologies are needed.[28]

Herzog et al were the first to use piezoelectric accelerometers for the vibrating signals, finding that skin-mounted accelerometers can accurately measure "bone vibration." Subsequently, accelerometer usage was found to be valid in accurately locating the source of the PS.[2,4] That is, using accelerometers, the authors analyzed the sound signals by a spatial differentiation algorithm, reporting multiple PSs (range 2-6) for each HVLA thrust manipulation with a 50% accuracy on the target segment of the spine for both the thoracic and lumbar spine.[4] More recently, Cramer et al, using a complex system of 9 accelerometers read by an oscilloscope, found multiple PSs from the same ZJ. The authors found that most PSs (93.5%) were reordered on the upper ZJs with a 71% target accuracy (ie, with a range error of 3 adjacent segments).[2]

Recently, another research team attempting to improve the sound signal processing methodology proposed a time-frequency analysis. The sound wave signals were recorded by skin-mounted microphones (ie, on C1-2 segment) and accelerometers (ie, on T1-2 segment) and then processed by using the short-time Fourier transform and analyzing the produced spectrograms.[8,26] Time-frequency analysis is a widely adopted method in monitoring different fields such as radar signals,[29,30] myoelectric signals,[31,32] and sound signals.[33,34] The aforementioned studies[2,4] did not apply it because they were aimed at investigating the PS phenomenon only by sensing the presence or absence of sound signals (ie, the actual sound releases) and then counting the number of reported PSs and determining their location. Otherwise, applying the time-frequency analysis permits one not only to observe with a much higher precision than the previously mentioned features directly on the spectrograms, but also to calculate the duration of the PS phenomenon and to directly determine its correlation with the HVLA thrust manipulation delivery. In addition, time-frequency analysis could allow monitoring the frequency components of the sound produced by the PS phenomenon. However, in this work, we did not focus on such an aspect. Further research will be carried out in this direction to extract additional information.

To the best of the authors' knowledge, this is the first study to identify the side of joint PS during lumbar HVLA thrust manipulation and the last of a series of 3 studies on different body regions using a time-frequency analysis with the goal of improving the methodology in studying the PS phenomenon.

Therefore, the purpose of this study was to observe from which side of the spine the PSs were emanating during lumbosacral HVLA thrust manipulation. Secondary aims of the study were to calculate the duration of a single lumbosacral thrust manipulation procedure and the average number of popping sounds after lumbosacral HVLA thrust manipulation.

Methods

Participants

Thirty-four asymptomatic participants (17 female and 17 male) aged between 18 and 65 years were recruited by convenience sampling from a private physical therapy outpatient clinic in Florence, Italy during November 2013. For participants to be eligible, they had to have experienced no low back or pelvic pain over the past 3 months.

Because of the absence of comparative data of the novel analysis methodology (ie, time-frequency analysis) and based on previous studies [12,14,18,21] on the topic, the authors did not run a sample size calculation (ie, descriptive analysis).

The ethics committee at the Universidad Rey Juan Carlos, Madrid, Spain, approved this study. All participants provided written informed consent before their participation in the study.

Participants were excluded if they exhibited 1 of the following: any red flags (tumor, fracture, metabolic diseases, rheumatoid arthritis, osteoporosis, resting blood pressure greater than 140/90 mmHg, prolonged history of steroid use, etc); presented with neurologic signs consistent with nerve root compression (muscle weakness, diminished deep tendon reflex, or altered sensation to pinprick in any dermatome); presented with a diagnosis of lumbar spinal stenosis; exhibited bilateral lower-extremity symptoms; had evidence of central nervous system disease (hyper-reflexia, sensory disturbances in the hand, intrinsic muscle wasting of the hands, unsteadiness during walking, nystagmus, loss of visual acuity, impaired sensation of the face, altered taste, the presence of pathological reflexes); had a history of recent trauma; or had prior surgery to the thoracic spine, low back, or pelvis.

Fig 1. *High-velocity low-amplitude thrust manipulation directed to the articulation of the left lumbosacral (L5-S1) junction.*

Manipulative Physiotherapist

A single US-licensed physical therapist performed all of the lumbosacral HVLA thrust manipulations in this study. At the time of data collection, the physical therapist had completed a postgraduate Master of Science in Advanced Manipulative Therapy, had worked in clinical practice for 14 years, and routinely used lumbosacral HVLA thrust manipulation in daily practice.

Lumbosacral Junction HVLA Thrust Manipulation Technique

A single "mamillary process body drop" HVLA thrust manipulation directed to the left lumbosacral junction (L5-S1) with the patient side lying was performed (Fig 1). For this technique,[35] the short lever was produced by having the therapist's hypothenar eminence of the right (ie, caudal) hand contact the left sacral base just medial (ie, 2 fingerbreadths lateral to midline) to the left posterior-superior iliac spinous. As the patient was rolled forward, the long lever was engaged by having the therapist place his anterior thigh over the patient's lateral thigh and lateral pelvis. To localize the forces

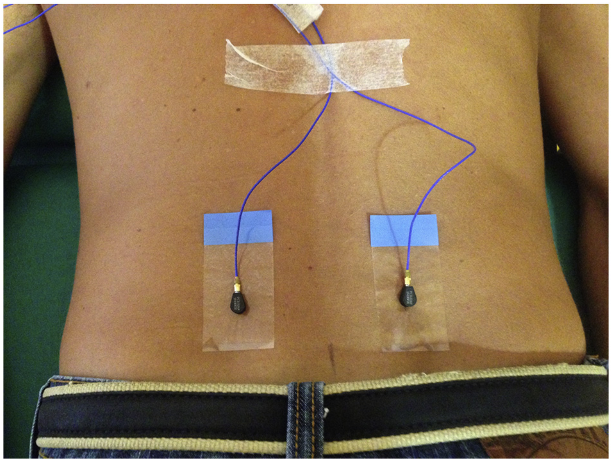

Fig 2. *Bilateral placement and securing of skin-mounted accelerometers 25 mm lateral to the midline of the left lumbosacral (L5-S1) interspace.*

to the left L5-S1 articulation, secondary levers of flexion and counter-rotation to the thoracolumbar spine were used. While maintaining the secondary levers, the therapist performed a single HVLA thrust manipulation using the simultaneous delivery of the thrusting primary levers of rotation to the sacrum from the short lever and a body drop from the long lever (ie, from rapid descent of the therapist's body weight onto the patient's thigh and pelvis). In addition, and as part of the thrust, the operator's left (ie, cephalad) hand provided a counterforce to the patient's anterolateral pectoral region by pushing down to the table with cephalad and posterior traction force. This was repeated using the same procedure but directed to the right L5-S1 articulation. Before data collection, the target side and delivery order of the L5-S1 HVLA thrust manipulations were randomized using a table of randomly assigned numbers for all participants. Popping or cracking sounds were heard on all HVLA thrust manipulations; hence, there was no need for second attempts.

Accelerometer Placement and Sound Collection

Skin-mounted accelerometers were secured bilaterally 25 mm lateral to the midline of the L5-S1 interspace (Fig 2) before the lumbosacral HVLA thrust manipulation delivery. The accelerometers were connected to a data acquisition system (Focusrite Scarlett 2i2 [Focusrite Audio Engineering Ltd, High Wycombe, United Kingdom], 96 KHz, 24-bit conversion) and a MacBook Pro (Apple, Cupertino, California) laptop with Audacity software for audio acquisition[25] with a sampling frequency set at 96 000 Hz. The Audacity software normalized automatically the audio energy to values ranging between -1 and +1 (no unit of measurement). Then, all participants randomly received HVLA thrust manipulations targeting the left (L5-S1) lumbosacral junction on both sides. The sound wave signals and resultant PSs were recorded for later data extraction and analysis.

Data Extraction

The sound signals were processed by short-time Fourier transform to obtain the spectrograms of each thrust manipulation. A spectrogram provides a representation of the energy of a signal as a function of time and frequency. A color map has been used to express the energy of the sound represented with time on the x-axis and frequency on the y-axis (Fig 3). Then, the spectrograms were analyzed to evaluate the frequency content of both signals over time. The epoch length was set to 0.78 milliseconds (ie, 75× the sampling rate) with a 0.1% overlap between adjacent epochs, resulting in a frequency resolution of 94 Hz. The frequency scale was set between 10 Hz and 23 kHz because this is the audible spectrum for a human being (including a small margin of error).

Data Processing

The sound in every audio track was modeled as a digital signal with the energy varying discretely as a function of time. The left and the right channels, representing, respectively, the 2 recordings of the left and right accelerometers during a single HVLA thrust manipulation, were analyzed separately. A left and a right graph were obtained, representing the variation of the sound energy over time. However, for each person and for each manipulation, we did inspect them jointly to determine whether the popping phenomenon was an ipsilateral or contralateral event and whether it occurred on 1 side or on both at the same time. The graphs also permitted precisely summing the total number of pops during a single manipulation.

To isolate the time interval in which the manipulation took place, we first listened to the audio tracks of the left and right channels (relative to a single manipulation) using a stereophonic system. The peculiar sound emitted, together with visual inspection of the right and left graphs of the digital audio signal, allowed for easy recognition of such an interval. The correct time interval featuring the manipulation event was then confirmed and adjusted by decelerating the audio speed by a factor of 0.01 and listening to the track again. This allowed us to identify the beginning and the end of the thrust manipulations and also to identify how many PSs were present. More specifically, this operation permitted us to increase the temporal resolution of the human ear 100-fold, allowing us to discriminate and sum the total number of PSs.

The spectrograms show the "location" of the energy of the audio signals over time and over frequency jointly. Because we were interested in any PS occurring during the manipulation, independently on its different frequency contributions, the spectrograms were finally integrated over frequency to obtain 2 curves (1 per channel) with the time on the x-axes and the globally released sound energy on the y-axes. Such curves constitute the graphic representation used for analyzing the PS phenomena.

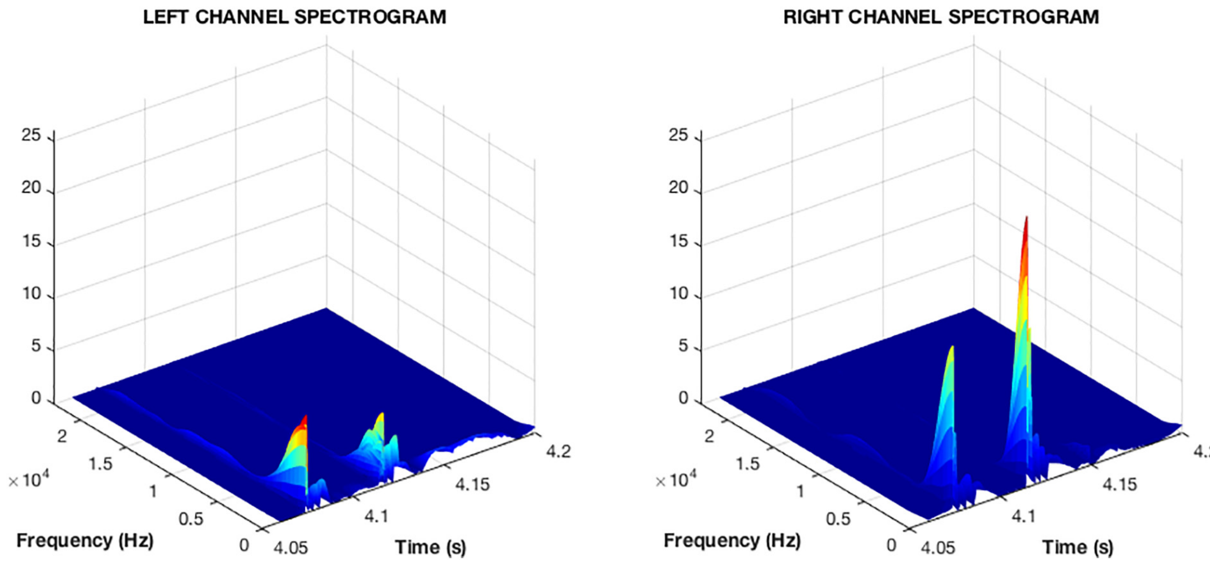

Fig 3. *Spectrograms for the left and right audio channels during lumbosacral high-velocity low-amplitude thrust manipulation. Vertical energy peaks represent individual pops.*

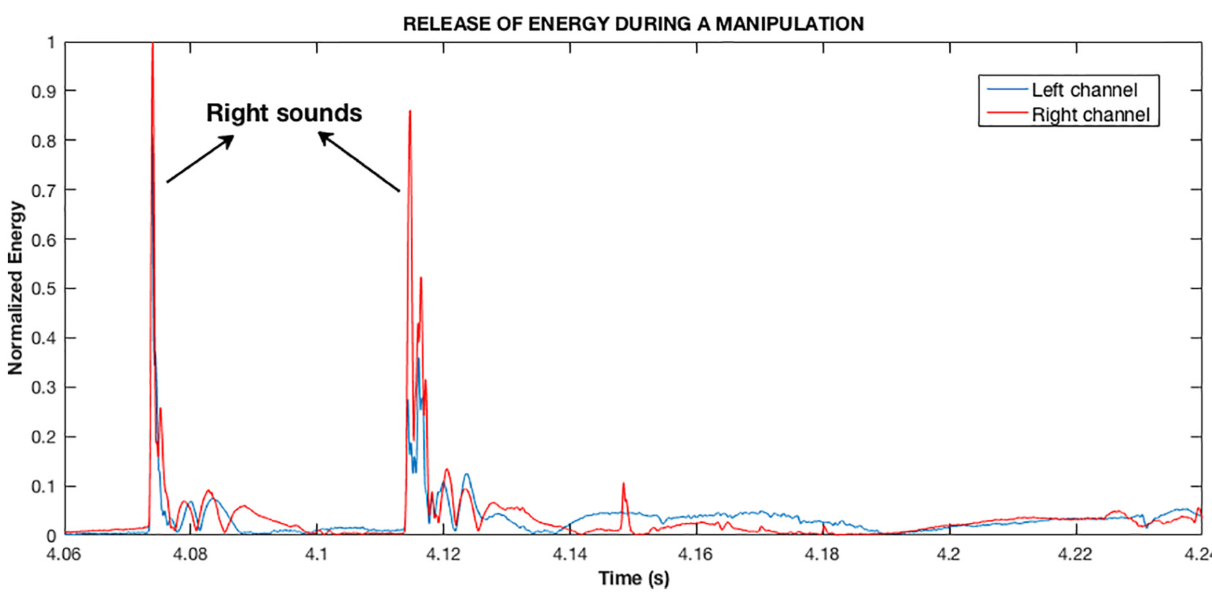

Fig 4. *Amount of energy released over time for the right and left accelerometry channels.*

Process for Counting the Number of PSs

The curves that represent the amount of released energy over time in both the left and right accelerometer channels were visually inspected to identify instantaneous bursts corresponding to PSs (Fig 4). The total number of PSs per manipulation was the sum of the number of energy bursts identified. In case of multiple consecutive (ie, overlap) energy bursts, we discriminated the single PS by measuring the time interval between the end of the descending phase of an energy burst and the beginning of the ascent of the subsequent burst. If this exceeded 2 epochs, then we considered the bursts as different PSs. Otherwise, we considered them part of the same PS. We choose 2 epochs as the threshold interval to distinguish between the 2 events to increase the margin of safety of 1 epoch to the minimum time interval necessary for 2 different peaks to be discriminated against each other, which coincides with the resolution of the spectrogram and is equal to 1 epoch. That is, off the 60 lumbosacral HVLA thrust manipulations procedures, 320 PSs were recorded. Notably, because no previous studies used a time-frequency analysis to investigate the PS, it has not been possible to compare the used procedure with other ones or with a gold standard for reliability or accuracy.

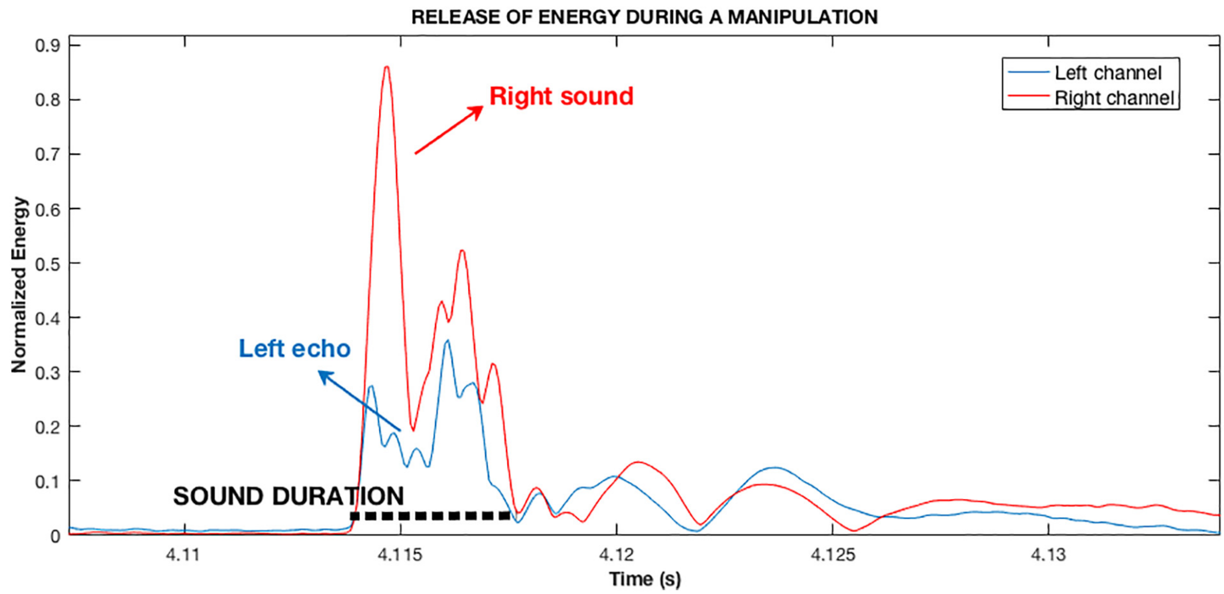

Fig 5. *The time interval used to calculate the duration of a single pop during cervicothoracic high-velocity low-amplitude thrust manipulation.*

Process for Determining the Side of the PS

The side of the PS was determined by inspecting each of the energy bursts for the right and left spectrograms. Because we computed graphs and quantified the amount of energy at each epoch separately for the 2 channels, the side of the PS could be immediately determined. As previously described,[2,4] in the event of simultaneous bursts on both the right and the left channels, we considered the PS as occurring on that side where the burst that began earlier and had the higher energy value was reported. That is, this means that the sound wave generated by the PS reached the accelerometer placed on this side before the one placed on the other side and experienced less dispersion (ie, the PS was physically nearer this side than the other). The burst sensed on the latter was discarded and not considered in the calculation of the average number and duration of a PS.

Process for Calculating the Duration of a Single Pop

For each of the 320 pops detected during 60 lumbosacral HVLA thrust manipulations, the time interval between the beginning of the ascent of the first energy burst and the end of the descent of the last energy burst of a PS event was considered the duration of a single pop (Fig 5).

Process for Calculating the Duration of the Thrust Manipulation

As described in our previous studies,[25,26] the duration of the thrusting procedure was considered the time interval between the beginning of first pop and the end of the last pop (Fig 6).

Data Presentation

Sound waves resulting from the lumbosacral HVLA thrust manipulations were displayed in graphical format. Each participant had 1 right and 1 left graph, describing each thrust procedure (ie, 2 channels per 2 graphs, namely 4 graphs in total for each participant). Means and standard deviations (SDs) were calculated to summarize the average number of pops, the duration of lumbosacral thrust manipulation, and the duration of a single PS. We compared the percentage of PSs occurring on each side during lumbosacral junction (L5-S1) HVLA thrust manipulation.

Results

Of the 320 total PSs during 60 HVLA thrust manipulations, 176 occurred ipsilateral and 144 occurred contralateral to the targeted L5-S1 articulation; that is, the PS was no more likely to occur on the ipsilateral than the contralateral side after right or left rotatory L5-S1 HVLA thrust manipulation. Moreover, distinct PSs occurred 98% of the time on the ipsilateral (upside) or the contralateral (downside) facet articulations, but very rarely (2% of cases) occurred at the same on both side during a single lumbosacral HVLA thrust manipulation.

All 60 lumbosacral HVLA thrust manipulations resulted in 2 or more audible joint PSs (range, 2-9) with a mean of 5.33 (95% CI: 4.82-5.85) distinct pops per lumbosacral HVLA thrust manipulation procedure. More specifically and on average, for each lumbosacral HVLA thrust manipulation procedure, 2.93 (SD 2.16) of the 5.33 pops (54.97%)

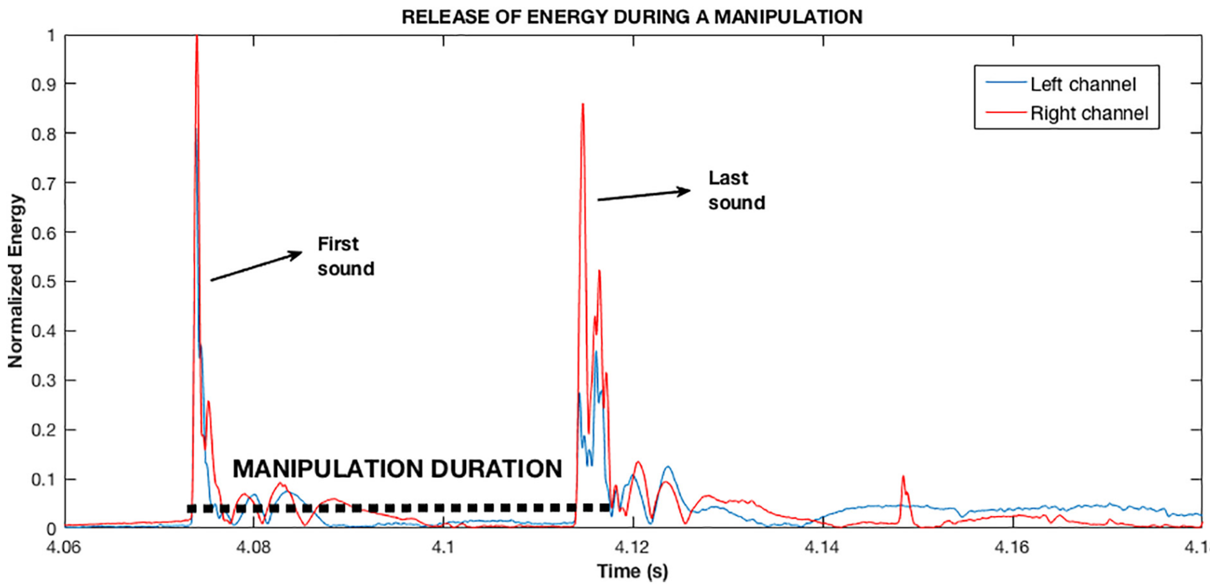

Fig 6. *The time interval used to calculate the duration of an high-velocity low-amplitude thrust manipulation to the lumbosacral junction.*

occurred on the side ipsilateral to the short-lever applicator of the physiotherapist (ie, the ceiling side), whereas 2.40 (SD 2.08) of the 5.33 pops occurred contralateral (45.03%).

Generally, bilateral PSs (ie, both side occurrence but not necessarily at the same time) were detected in 36 of 60 (60.0%) lumbosacral HVLA thrust manipulations and unilateral (ie, single side occurrence but not necessarily at the same time) PSs were detected in 24 of 60 (40.0%) thrust manipulations; that is, the PS was not significantly more likely to occur bilaterally than unilaterally. Nevertheless, during lumbosacral HVLA thrust manipulation targeting the right or left L5-S1 joint, the resulting PSs were 1.5× more likely to occur generally bilaterally than just unilaterally during a single HVLA thrust manipulation delivery.

Two distinct PSs were produced in 6 (10.0%) of the manipulations, whereas 7 (11.7%), 8 (13.3%), 9 (15.0%), 11 (18.3%), 13 (21.7%), 1 (1.7%), and 5 (8.3%) manipulations produced 3, 4, 5, 6, 7, 8, and 9 distinct PSs, respectively. Thirty-four participants received 60 manipulations (ie, 2 on each participant); however, data were not retrievable for 12 procedures, thus data for 60 manipulations in 34 participants were analyzed.

The mean duration of a single pop was 2.69 milliseconds (95% CI: 0.95-4.59), and the mean duration of a single lumbosacral junction HVLA thrust manipulation was 139.13 milliseconds (95% CI: 5.61-493.79).

Discussion

Side of the PS

Three previous studies[8,17,28] investigated the side of the joint PS associated with cervical spine manipulation; however, none of them involved the lumbosacral junction.

Our results indicate that the PS was more likely to occur on a single side than on both sides. Moreover, the PS was no more likely to occur ipsilateral (ie, upside facet joint) to the short-lever applicator of the manipulative physiotherapist after right or left L5-S1 HVLA thrust manipulation than the contralateral side (ie, downside facet joint). That is, PSs occurred in 54.97% of the 60 lumbosacral HVLA thrust manipulations on the side ipsilateral to the short-lever applicator of the physiotherapist (ie, the ceiling side), whereas 45.03% occurred at the contralateral side.

The results of our study are difficult to compare directly with the previous studies[2,17,25,28] on this topic. Similarly, Cramer et al[2] reported 93.5% of the PSs to have occurred on the upside facet articulations and with just 1.43 PSs per participant. However, Cramer et al only looked at the number of sound releases during the HVLA thrust manipulation for the purpose of identifying the side and number of popping events as it was done in this study.[2] Instead, our study aims not only to determine the side and the number of popping sounds, with a much higher accuracy permitted by the application of the sound-frequency analysis, but also to calculate the duration of the pops and of the entire manipulation. The positioning of the accelerometers in the 2 studies was different. That is, we mounted accelerometers directly close to the target articulation (ie, 25 mm lateral to the midline of the L5-S1 interspace [Fig 2]), whereas Cramer et al[2] mounted 9 accelerometers that were placed on each patient (ie, 7 on spinous processes/sacral tubercles of L1-S2 and 2 placed 3 cm left and right lateral to the L4/L5 interspinous space). Previously, the same research group[4] taped accelerometers to the skin over the spinous processes of the spinal column of each participant. In this study, PSs were identified by assessing the shifts from the baseline of several accelerometer recordings by a computer oscilloscope. However, Ross et al[4] was able only to identify the level of the PS (not the side) by the order in which the recording line for each accelerometer deviated from the baseline using a spatial differentiation algorithm.

We found that the PS was no more likely to occur on the ipsilateral than the contralateral side to the short-lever applicator of the manipulative physiotherapist.

Number of Pops per Thrust

Similarly to our results, Ross et al[4] found 1 to 6 audible PSs per lumbar HVLA thrust manipulation. In 8 of 30 participants, Cramer et al[2] further found 2 or more PSs per lumbar HVLA thrust manipulation. There is some evidence to suggest that a PS is required to achieve the proper force during a HVLA thrust manipulation. However, it is impossible to recognize with certainty which joint underwent the PS process during a HVLA thrust manipulation.[36,37]

Nevertheless, in our study we observed sounds composed of single energy releases and also sounds composed of multiple energy releases—that is, single versus multipeak sounds. Consistently with previous studies,[27,28] we identified high-frequency sounds, low-frequency sounds, and sounds of multiple frequencies.[26] Therefore, as opposed to a single model being able to explain all of the audible sounds during HVLA thrust manipulation, the possibility remains that several popping phenomena may be occurring simultaneously.

Duration of an Individual Pop

We found the mean duration of a single pop to be 2.69 milliseconds during a lumbosacral HVLA thrust manipulation. This value is very similar to the 4-millisecond duration reported by Reggars and Pollard[28] for the "average length of joint crack sounds," the 5.66-millisecond duration for the mean duration of a single pop during upper cervical thrust manipulation, and 4.13 milliseconds during cervicothoracic junction thrust manipulation reported by Dunning et al.[25,26] Although Herzog et al[3] reported triphasic "cavitation signals" with a mean duration of 20 milliseconds, it is unclear whether this value represents a single PS or multiple PSs. However, in our study, we calculated the time interval between the beginning of the ascent of the first energy burst and the end of the descent of the last energy burst of a PS event for the duration of a single pop. The interval was therefore representative of the duration of 260 individual PSs detected during 60 lumbosacral thrust manipulation procedures.

Duration of the Thrust Procedure

Similar to Dunning et al,[25,26] but unlike 3 previous studies,[3,5,38] we used the time interval between the beginning of first pop and the end of the last pop to represent the duration of the actual thrusting procedure from onset to arrest; nevertheless, we found the mean duration of a single lumbosacral HVLA thrust manipulation to be 139.13 milliseconds (95% CI: 5.61-493.79), a value that is consistent with the 150 milliseconds reported by Herzog et al[3,39] for a lumbar spine thrust manipulation.

Clinical Relevance of the PS

Spinal manipulative therapy has been recommended for the management of spinal conditions.[40-44] Few authors in the past suggested that the PS after a lumbar HVLA thrust manipulation delivery was not necessary to determine clinical outcome changes.[45-47] Nevertheless, the PS is considered a technical indicator for a successful HVLA thrust manipulation delivery.[2-7]

Moreover, anecdotal evidence suggests an association between clinical outcome changes and the PS. In fact, many clinicians and research teams still repeat the HVLA thrust manipulation if the PSs did not emanate.[2,6,7,9-14] In addition, Evans and Lucas[1] found that audible PSs within the affected joint is 1 of the 5 empirically derived features necessary for a valid thrust manipulation. In other words, the audible popping that "occurs within a joint" should be present to satisfy the proposed manipulation criteria.[1]

Thus, the traditional expectation of achieving just 1 single pop per HVLA thrust manipulation in the lumbopelvic region is therefore not supported by the existing literature,[2,4,18,25,26,28,48] and 1 pop should no longer be taught as the goal or expectation in conventional manual therapy training programs. Nevertheless, to date, no study has investigated the clinical significance (ie, its relationship to pain and disability) of the PSs after HVLA thrust manipulation in patients with low back pain.

Ross et al[4] found that the average error from the targeted joint was at least 1 vertebra away from the target (ie, 5.29 cm). However, because most of the procedures resulted in multiple PSs, at least 1 of those was emanated from the targeted joint. Thus, because the accuracy of both the motion palpation[49,50] and the capability to manipulate the targeted segment[4] were shown to be insufficient to be used in clinical practice, multiple PS manipulation seem to be the best science-based model. Moreover, understanding the side where the PSs emanate from will inform practitioners of spinal manipulative therapy in better selecting the appropriate technique.

Limitations

The results of this study may not be generalizable to other spinal regions because of differences in the morphology of the lumbosacral junction. Furthermore, the results of our study cannot be generalized to lumbosacral manipulation techniques that use different combinations of primary and secondary, physiologic, or accessory component levers. One further limitation of this study was that only 1 practitioner (force development, thrust style, experience, physical characteristics, profession, etc) administered all of the lumbosacral thrust manipulations; although this enhances internal validity, it also compromises generalizability. As well, a possible confounder is that a single cavitation on one side of the body can be sensed by both accelerometers. Moreover, although the attempt to implement a novel methodological analysis may represent a step forward, it is limited because it is not still validated in this field.

Future Studies

Future research should determine the vertebral level or levels at which the PSs are emanating from and investigate the clinical significance of the PS phenomenon after lumbosacral HVLA thrust manipulation in patients with mechanical low back pain. In addition, future trials should investigate whether a relationship exists between the number of PSs and the degree of change in the clinical outcomes of pain and disability in these subgroups of patients. Future studies should also consider employing a mixed-methods qualitative and quantitative design to better deconstruct the multiple popping phenomena that appear to be occurring simultaneously during HVLA thrust manipulation. Finally, a deeper understanding of the mechanism behind thrust manipulation and the PS phenomenon will address a better design for future primary studies (eg, randomized controlled trial) and provide an explanation of the inconclusiveness or differences between the results of many randomized controlled trials. We suggest that spinal manipulation therapy usage may need a science-based paradigm shift.

Conclusion

Based on our findings, spinal manipulative therapy practitioners should expect multiple PSs that most often occur on the upside or the downside facet articulations when performing HVLA thrust manipulation to the lumbosacral junction (L5-S1). However, whether the multiple PSs found in this study emanated from the same joint or the adjacent ipsilateral or contralateral facet joints remains unknown. That is, a single model may not be able to explain all of the audible sounds during HVLA thrust manipulation. Thus, the novel advance in knowledge on this topic may inform practitioners of spinal manipulative therapy in better selecting the appropriate HVLA thrust manipulation 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): F.M., J.D., A.Z.

Design (planned the methods to generate the results): F.M., J.D., A.Z.

Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): F.M., J.D.

Data collection/processing (responsible for experiments, patient management, organization, or reporting data): F.M., J.D., A.Z., R.I., N.Z.

Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): F.M., J.D., A.Z.

Literature search (performed the literature search): F.M., J.D.

Writing (responsible for writing a substantive part of the manuscript): F.M., J.D.

Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): R.B., C.F.d.l.P.

Practical Applications

- The traditional manual therapy approach of targeting a specific facet joint during the delivery of HVLA thrust manipulation may not be feasible.
- Based upon the findings of this study, manual practitioners should expect multiple PSs when performing HVLA thrust manipulation.

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