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Manual Therapy xxx (2009) 1–6

Contents lists available at ScienceDirect

Manual Therapy

journal homepage: www.elsevier.com/math

Original Article

A descriptive study of the force and displacement profiles of the toggle-recoil spinal manipulative procedure (adjustment) as performed by chiropractors

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ARTICLE INFO

Article history:
Received 20 October 2008
Received in revised form
24 June 2009
Accepted 10 July 2009

Keywords:
Manipulation
Chiropractic
Neck

ABSTRACT

The aim of this study was to determine the variability of the thrust parameters produced by practitioners performing a high velocity spinal manipulative therapy technique (toggle-recoil) normally applied to the neck.

Fourteen participants performed three thrust trials, separated by >30 minutes, on a patient simulation device. Force and displacement generated during the thrusts were simultaneously recorded and analysed off line. Peak thrust force ranged from 18.2 to 246 N with a mean of 111.2 N (SD 48.8). Time to peak thrust force ranged from 20 to 100 ms, mean 67.5 ms (SD 13.1). Peak thrust displacement ranged from 6.1 to 28.9 mm, mean 24.1 mm (SD 4.9) and time to peak thrust displacement ranged from 22.5 to 105 ms, mean 59.4 ms (SD 13.8).

This study demonstrates that the force and displacement induced by any individual practitioner on a simulator can vary by up to 50% during a toggle-recoil thrust. Furthermore, different practitioners may vary in their force by as much 100% and in displacement by 50% when the toggle-recoil spinal manipulative procedure is performed.

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1. Introduction

Spinal manipulative therapy (SMT) refers to a variety of manual procedures used by chiropractors, osteopaths, physiotherapists and some medical practitioners to treat their patients. Various terms are used to categorise these procedures on the basis of either the intended effect on the joints of the vertebral column (c.f. Sandoz, 1989) or the perceived biomechanical profile (Bartol, 1992). It is generally accepted that spinal manipulation refers to a procedure that involves a single high-speed thrust and that mobilisation involves a single or repetitive (oscillatory) protocol that is relatively slow (for review see Lee et al., 2000). Previous studies have examined biomechanical characteristics of manipulative procedures applied to different regions of the vertebral column (Kawchuk et al., 1992; Herzog et al., 1993; Solinger, 1996; Vicenzino et al., 1999; Ngan et al., 2005). These studies typically define the force-time profiles and have shown that this characteristic depends on the technique being used and the region in which it is being applied (for review see Lee et al., 2000).

Chiropractors, in contrast to other practitioners, refer to their manipulative procedures as vertebral 'adjustments', in part to reflect the intent of the procedure to have a "...controlled force, leverage, direction, amplitude and velocity directed at specific joints or anatomic regions." (Gatterman, 2005). This implies that the practitioner has the ability to perform the procedure with the appropriate speed, depth and force. A particularly important point when the SMT is applied to the neck given that there is some concern about the efficacy of neck manipulation when performed alone (Gross et al., 2004) and adverse events are known to be associated with SMT of the neck (Thiel et al., 2007). While no two patient presentations are likely to be the same it is not unreasonable for a patient to expect that the practitioner can perform a given manipulation in a predetermined and consistent manner.

One SMT technique developed and used by chiropractors on the neck, is the toggle-recoil upper cervical technique (Stephenson, 1927). This form of SMT is used by some 25% of the chiropractic profession in North America and about 7% of patients presenting to chiropractors are treated with this technique (Christensen and

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doi:10.1016/j.math.2009.07.003

Please cite this article in press as: Graham BA, et al., A descriptive study of the force and displacement profiles of the toggle-recoil spinal..., Manual Therapy (2009), doi:10.1016/j.math.2009.07.003

Kollasch, 2005). The thrust used in this technique is known as a toggle-recoil adjustment and is sometimes used together with a specially designed table that allows the head piece on which the patient's head rests to drop away as the thrust is applied. This technique involves a high velocity thrust, typically directed at the C1 or C2 vertebra of the patient when lying passively in the lateral decubitus position (Grice, 1980). The patient's head is supported by a head piece (See Fig. 1A) which can be held static or, alternatively, set to drop away (12.7 mm) under the patient's head when the thrust is applied to the patients neck. The engagement of the drop head piece together with the correct patient placement is intended to introduce a sheer force to the upper cervical vertebral column as the motion of the head piece abruptly stops. The technique requires a controlled thrust in order to avoid inappropriate and or excessive displacement of the upper cervical region.

The aim of this study was to determine the inter- and intra-practitioner variability of the thrust parameters resulting from a toggle-recoil adjustment thrust using a patient simulation device capable of recording the thrust force and displacement.

2. Methods

This study was approved by the Institution's Human Ethics Committee. Volunteers responded to a notice calling for participants to perform toggle-recoil adjustments (TRA) on a patient simulation device (PSD) which allowed measurement of the displacement (depth), force and time profiles. All participants gave informed consent and completed a questionnaire concerning their training in the toggle-recoil adjusting technique, years in practice, frequency of use of TRA and handedness. Fourteen participants were recruited for the study.

A simple chiropractic adjustment training device (Speeder Board, Davenport, USA, see Fig. 1B) which incorporates a hinged lever (10 degrees of rotation allowing up to 29 mm excursion) positioned over a spring (Spring constant $(k) = 5.88$ N/mm), simulating the stiffness of a patient's neck, was modified to allow real-time measurement of the force and depth of the applied TRA thrust (Fig. 1C). This PSD incorporated a purpose built load cell (output sensitivity of 35mV/Newton of applied load) allowing measurement of the force (error $\leq 12\%$ for

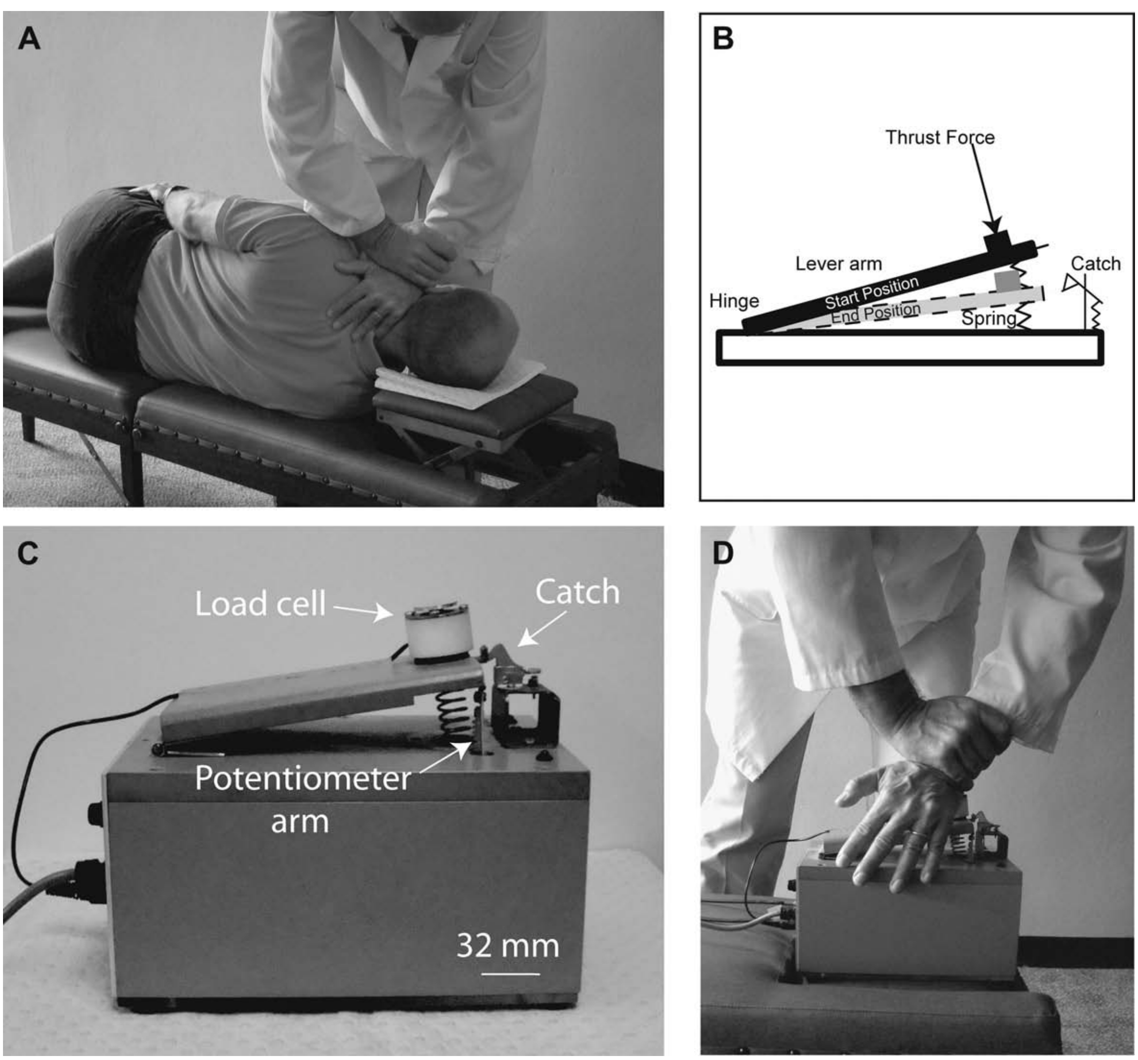

Fig. 1. Panel A is a photograph depicting the typical stance and contact adopted by a practitioner when performing a toggle-recoil procedure directed at the patients' first cervical vertebra. Panel B is a schematic depicting the components of a typical patient simulation device (PSD) used to teach and practice the toggle-recoil procedure. The practitioner's toggle-recoil thrust (Thrust Force) is directed at the PSD in the start position. This puts the hinged lever arm in motion against a spring simulating the mechanical resistance in a patient's neck. The thrust force displaces the lever arm. The travel of the lever arm can be limited by engaging a spring loaded catch which stops the leaver arm returning to the start position. Panel C shows a photograph of the PSD used in this study. The load cell used to measure force and arm of the potentiometer (pp) used to measure the displacement have been labelled. Panel D is a photograph of a practitioner using a left hand contact of the PSD in preparation to apply a toggle-recoil thrust to the PSD.

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a thrusting force applied at up to 9° obtuse to the load cell) imparted by the practitioners hand during a TRA thrust. Displacement during a thrust was measured using a linear potentiometer (output sensitivity of 38mV/mm deflection, error ≤ 3% over 29 mm displacement) attached to the hinged mobile lever (maximum 29 mm displacement). A data logger interface device allowed simultaneous measurement of the magnitude of thrust displacement and force as the board was depressed against the spring. Both force and displacement signals (voltage) were processed simultaneously using a 2 channel amplifier (MacLAb, ADInstruments, Sydney, Australia) and a desktop computer (Macintosh G3) running Chart V3.1s software (MacLab, ADInstruments, Sydney, Australia). Fig. 1D, shows a practitioner prepared to perform a toggle-recoil thrust on the PSD in the same manner it is performed clinically (see Fig. 1A). Fig. 2 shows a force and displacement record using the left and then right hand. A clip on the PSD used to prevent oscillation of the device following the thrust (see Fig. 1C) resulted in a DC off-set of the displacement curve at the end of the trace (Fig. 2 lower panels). Prior to each thrust the force and displacement trace on the PSD device were re-set to zero. Off-line analysis was performed to quantify the absolute force, displacement, the force-time and displacement-time profiles during the delivery of the TRA thrusts by the practitioners.

In order to simulate clinical practice the PSD was positioned on a chiropractic side-posture adjusting table fitted with a drop-headpiece (Palmer-Thompson, Davenport, USA). The drop-head piece mechanism was disengaged to provide a stable platform for the PSD. Furthermore, the participants were instructed to perform a TRA on the PSD as though the chief investigator was the patient. Participants were given the opportunity to palpate the chief investigator's neck and to palpate the PSD before performing the TRA. This provided each participant with a common basis on which to formulate the motor commands necessary to perform the TRA. The participants undertook 3 trials with at least 30 minutes between each trial. Each trial involved the participant performing a left and then right sided TRA on the PSD.

2.1. Analysis

Each TRA thrust was characterised by measuring the minimum and maximum values from force and displacement curves. The

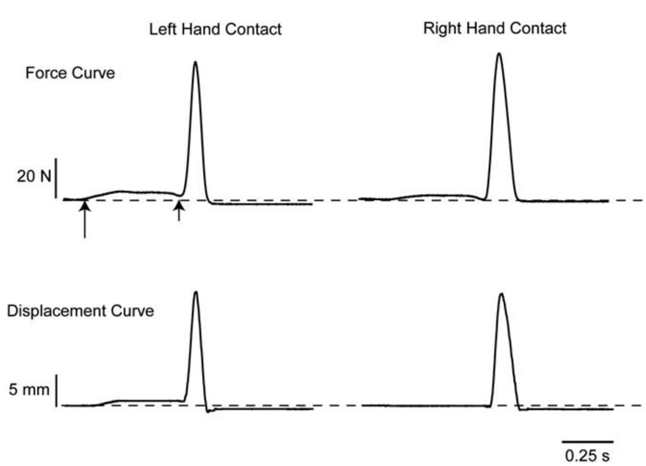

Fig. 2. Force (upper traces) and displacement (lower traces) curves generated by single participant are shown. The left panel are traces produced when contacting the patient simulation device (PSD) with a left hand contact and the right panel shows the traces produced with a right hand contact. The long arrow identifies the point in time that the participant contacted the PSD and applied a pre-load. The short arrow marks the commencement of the thrust. Note the difference in the pre-load (and displacement) recorded for the left (left panel) and right (right panel) hand contacts. Dashed lines are zero.

times at which these events occurred were recorded. In addition to descriptive statistics (mean ± SD), the respective null hypotheses were tested using the software package SigmaStat V2.03 (SPSS Inc, Chicago). All data were tested for normality using the Kolmogorov–Smirnov test (with Lilliefors' correction). If normally distributed, the *t* test and one-way analysis of variance were used. When data were not normally distributed, the Mann–Whitney Rank Sum Test was used. A probability of $P < 0.05$ was designated to be significant.

We undertook a post hoc analysis of the sensitivity of our study (Glantz, 1997) to detect differences between less experienced (student) and more experienced (practitioner) persons in respect of force and depth of their thrusts by undertaking power and sample size calculations. We used the software package SigmaStat V2.03 (SPSS Inc, Chicago) to perform the calculations using the means and standard deviations from our depth and force data. We used an alpha of 0.05 and determined sample size using a power of 0.8.

3. Results

Fourteen participants were recruited for the study. The data from 1 participant was excluded because the participant only completed one trial. Five of the participants were registered practitioners and eight were final (5th) year chiropractic students. Practitioners had been in chiropractic practice an average of 18.3 (SD 3.9) years. Two practitioners reported they used TRA < 2 times per week, one used TRA 5–10 times per week, 2 practitioners performed TRA 2–5 times per day, and one 5–10 times per day. The practitioner who only completed one trial had reported using the toggle-recoil <2 times per week. Students had completed their training in TRA on average 1.4 (SD 0.5) years prior to participating in the study. Five of the students reported performing TRA <2 times per week, and 3 performed TRA 5–10 times per week. Each participant spent between 3 and 5 minutes palpating the neck of the chief investigator and then the PSD before performing their toggle-recoil thrusts. Two participants completed only 2 trials.

3.1. Force

Fig. 2 shows a trace of force displacement recorded in this study from one participant. It was rare not to record a small pre thrust load (range 0.002–5 N) when the participants hand first contacted the PSD, see top panel in Fig. 2. The peak force generated by the TRAs ranged from 18.2 to 246.1 N (mean peak force 111.2 N (SD 48.8)) for all TRA ($n = 74$) performed in this study. There was no significant difference between either the maximum ($P = 0.852$) or the minimum ($P = 0.852$) peak force of TRAs performed by students compared to the practitioners. The greatest range for peak forces generated by an individual participant over their respective 3 TRA trials was 123.4 N and the minimum was 5.6 N with a mean range of 41.5 N (SD 27.8) across all participants. There was no significant difference between the peak forces developed with a left hand contact compared to a right hand contact ($P = 0.695$). Although practitioners appeared to achieve more reproducible forces over the 3 TRA trials (see Fig. 3 small ranges), there was no significant difference between the practitioners and students. This may be explained by the small number of practitioners included in the study.

The time to peak TRA force from the first detection of force applied to the PSD ranged from 20 to 100 ms for all trials ($n = 74$) with a mean of 67.5 ms (SD 13.1). The time to peak TRA force for students ranged from 20 to 100 ms with a mean 70.7 ms (SD 13.9). In contrast, the time to peak TRA force for the practitioners was significantly faster ($P = 0.004$) ranging from 37.5 to 77.5 ms with a mean of 61.5 ms (SD 9.1).

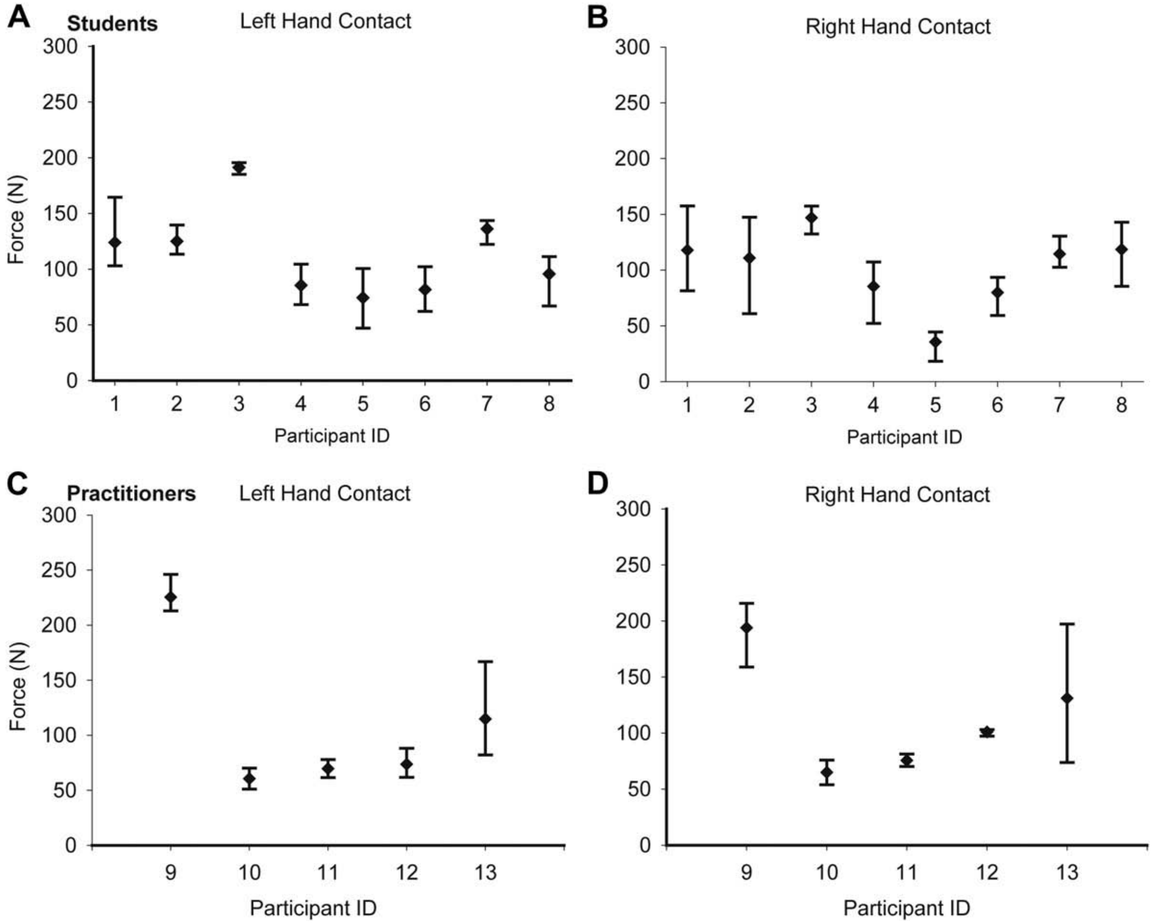

Fig. 3. Plots summarise the range (bars) and means (diamonds) of the force (N) generated at each of three trials (thrusts) for each individual participant in this study. **A** shows the force for individual students when using a left hand contact and **B** when they use a right hand contact. **C** and **D** show the forces when individual practitioners used a left (**C**) or right (**D**) hand contact to perform the thrust.

3.2. Displacement

Fig. 4 summarises the thrust displacements. The mean TRA thrust displacements for all TRAs ($n = 74$) was 24.1 mm (SD 4.9) and the maximum TRA thrust displacement ranged from 6.1 to 28.9 mm. However, the PSD had a physical maximum displacement of 29 mm and on two occasion (see Fig. 4; panel A student #7, and panel D practitioner #9) the thrust resulted in maximum displacement. Presumably the thrust depth on these occasions would have exceeded 29 mm, thus these trials were excluded from analysis of TRA displacement. The maximum TRA thrust displacement for student trials ($n = 47$) ranged from 6.1 to 28.8 mm with a mean of 23.6 mm (SD 5.5) and was not significantly different ($P = 0.541$) to practitioner trials ($n = 25$), range 15.8 to 28.9 mm, mean of 24.8 mm (SD 3.5). The variability in TRA trials displacements for any individual ranged from 1.2 to 16.9 mm. The greatest range of displacement for any individual over 3 TRA thrust trials was recorded by a student (16.9 mm) and least by a practitioner (1.2 mm).

Time to develop peak TRA displacement for all trials ranged from 22.5 to 105 ms with a mean of 59.4 ms (SD 13.8). Time to peak TRA displacement for student's ($n = 49$) ranged from 22.5 to 105 ms with a mean of 61.8 ms (SD 13.9). The time to peak TRA displacement for practitioner's ($n = 25$) ranged from 35.0 to 82.5 ms with a mean of 55.0 ms (SD 12.6). Thus, as with time to peak TRA force, practitioners reached peak TRA displacement significantly faster ($P = 0.041$) than the students.

There were too few left handed participants in this study ($n = 2$) to determine if handedness influenced the force or displacement (Power of <0.8).

3.3. Power calculations

The study was underpowered to detect a statistical difference in the force (Power = 0.06) or depth (Power = 0.08) between students and practitioners with any certainty (alpha = 0.05; power > 0.8), if one actually existed (Glantz, 1997). To detect a difference between students and practitioners of 10% or greater in force (i.e. ≥11.7 N) or depth (i.e. ≥2.4 mm), with a high probability (Power ≥ 80%), we would need to have studied at least 51 practitioners and 51 students regarding depth and 139 practitioners and 139 students in regard to force.

4. Discussion

4.1. Validity of PSD

The mean peak force recorded in this study (111 (SD 49) N, $n = 74$) is similar to the peak force reported using a flexible pressure mat (117 (SD 16) N, $n = 2$) interposed between a practitioner's thrusting hand and the patient's neck during the performance of the same SMT procedure used in the current study (Kawchuk et al., 1992; Herzog et al., 1993). This suggests that the PSD used in this study provides a reasonable model for assessing the clinical

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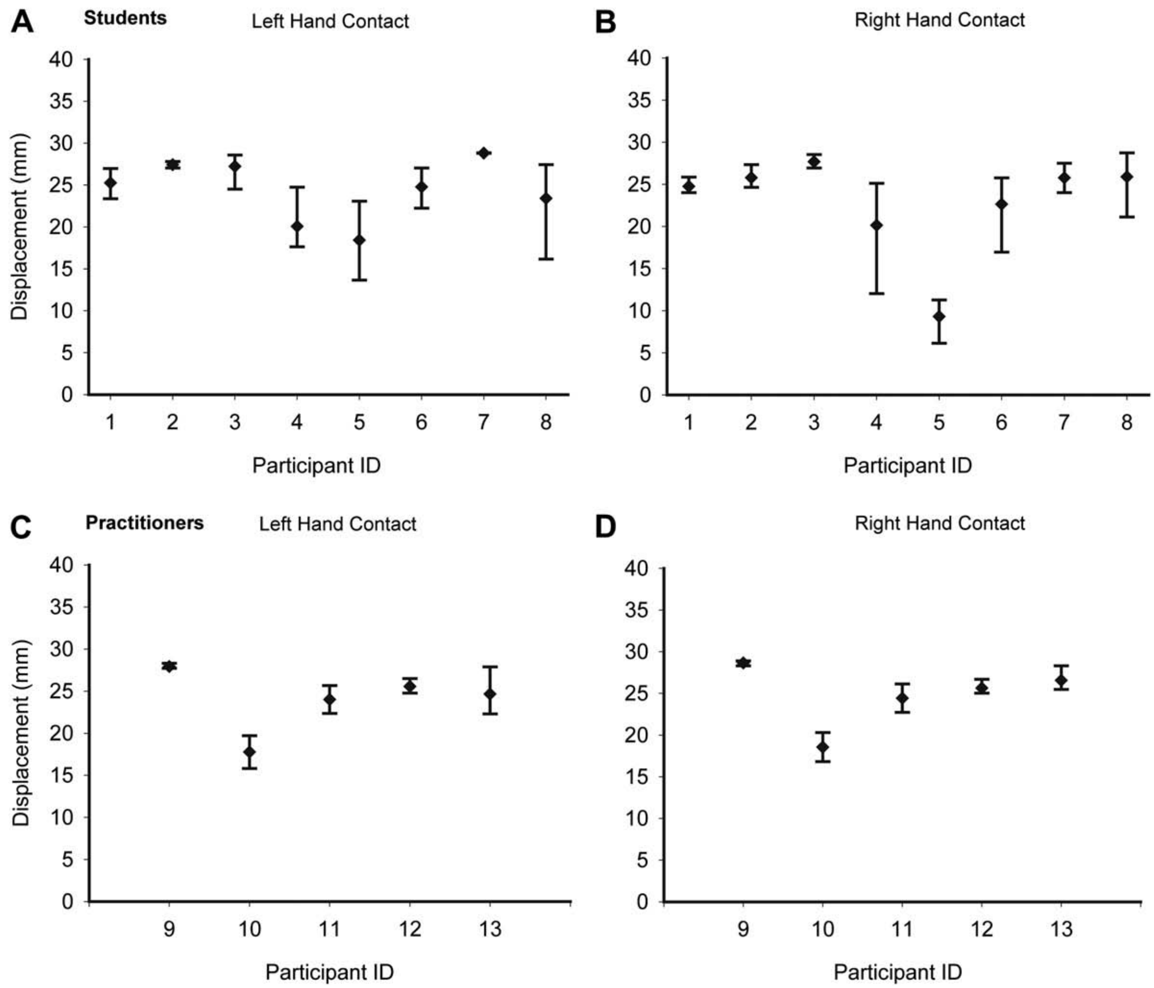

Fig. 4. Plots summarise the range (bars) and means (diamonds) of the displacement (mm) generated at each of three trials (thrusts) for each individual participant in this study. **A** shows the displacement generated by individual students when using a left hand contact and **B** when they use a right hand contact. **C** and **D** show the displacements when individual practitioners used a left (**C**) or right (**D**) hand contact to perform the thrust.

application of this form of SMT when applied to the neck. The inherent error of the force measurement for the PSD device we used was <12%. That is, at worst, our data values may be ±13 N which is smaller than the standard deviation of force reported by Kawchuk et al. (1992) when using the force mat (technical error unreported) directly on human subjects.

An important factor capable of influencing force and displacement profiles during TRA is the resistance against which the thrust is performed. Existing reports describing whole cervical spine stiffness, and thus the resistance to a TRA thrust, are fraught with problems associated with measurements made on post mortem tissue placed in frames that, in and of themselves, impact significantly on the recorded stiffness (Nightingale et al., 2004). Furthermore, they typically focus on compression loads and rotational or translational forces (cf. Moroney et al., 1988). Snodgrass et al. (2007) report that the mean posterior to anterior stiffness for the cervical spine at the level of C7 is slightly stiffer (7.03 N/mm; 95% CI 6.50–7.57) than at the level of C2 (4.58 N/mm; 95% CI 4.30–4.85). However, we are not aware of any *in vivo* measures of neck stiffness when the body is in the lateral decubitus posture with the head supported. Theoretical stiffness calculations for the cervical region range from 4.4 to 44 N/mm (Solinger, 1996). The spring in our PSD had a spring constant (k) within this range (5.88 N/mm). Despite this, the mean time to maximum force we report (67.5 (SD 13.1) ms; range 20–100 ms) is slightly greater than those reported by Herzog's group (47.5 (SD 14.7) ms; range 90–120 ms) (Kawchuk et al., 1992; Herzog et al., 1993). The use of a drop headpiece in the Herzog studies, but not ours, provides a possible explanation for this discrepancy. Once in motion, a drop headpiece potentially shortens both the time to peak force and total duration of the contact force applied to the subjects.

Our small preload force (<5 N) are consistent with Kawchuk et al.'s (1992) study of this form of SMT performed directly on humans. These are quite different to the preload forces of other SMT techniques applied elsewhere in the vertebral column and pelvis which are of the order of 139 (SD 46) N in the thoracic region and 88 (SD 78) N over the sacroiliac joint (Herzog et al., 1993). Given this, and the observations above we are confident that the PSD used in this study is adequate to simulate and assess the force and displacement profiles during TRA thrust to the neck. Nevertheless, extrapolating our data to the human may not be appropriate as thrusting on living humans will no doubt introduce additional variables.

4.2. Kinematics and reproducibility of the TRA thrusts

Unique to this study was the simultaneous measurement of the displacement and force produced by the toggle-thrust. The PSD

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used in our study was designed to have a maximum depth of 29 mm in order to have at least double the displacement (12.7 mm) allowed by the drop head piece table (see above) on which the toggle-recoil technique is performed. This was done to avoid the PSD limiting the displacement occurring during the toggle-recoil thrust. There are no reports in the peer reviewed scientific literature concerning the rational for the displacement of the head-piece (or the distance it can travel, i.e. 12.7 mm). Our results suggest that the hands of the practitioner continue to apply force to the patient's neck once the head-piece becomes stationary. That is, the practitioners hands travel more than 12.7 mm and would impart additional forces to the patients neck above the sheer force produced when the drop-headpiece (and thereby head) stops at its limit of travel (12.7 mm). Although lateral bending is known to induce significant coupled motion in the cervical spine (Ishii et al., 2006), the vertebral kinematics resulting from a toggle-recoil SMT procedure performed with or without a drop head piece remain to be determined.

This study was designed to be descriptive rather than to formally test if there were differences between participants. The post hoc power and sample size calculations using the data obtained clearly indicate that larger numbers of participants are needed if the study is to be able to conclude, with confidence (Power $\geq$ 80%), a significant difference between groups based on experience. It also suggests that the variability in this study, including apparent outlier data (see Figs. 2 and 3), may not represent the true variability between practitioners. Nevertheless, this study provides new data on which to base the design of further studies regarding the toggle-recoil thrust.

Interestingly, the range of peak forces obtained in this study (18–246 N) were greater than those reported from toggle thrusts applied directly to patients (99–140 N) (Herzog et al., 1993). We recorded TRA thrusts from more practitioners ($n = 13$) compared to Herzog et al. (1993) ($n = 2$) and thus our data may better indicate the range of peak forces produced by chiropractors using this form of SMT. However, many (8/13) participants in our study had limited experience. It is also possible that some participants may have relied on one or other of palpating the chief investigator's neck or the PSD rather than both to develop the motor command necessary to produce the toggle-recoil thrust. Although there was no significant difference in the peak force generated by practitioners and students, the students were found to be significantly ($P = 0.004$) slower at developing peak force than the practitioners even given the small number of participants in this study. Thus, the student to practitioner ratio undoubtedly influenced some of our results. Nevertheless it is clear from the power and sample size calculations that a larger study is necessary to more rigorously test for differences between defined groups of participants.

It remains to be determined what kinematic parameters (force, depth or velocity) are adequate or requisite for any SMT procedure to result in a therapeutic benefit. However, this study suggests that the force and depth may vary from one toggle-recoil procedure to the next by as little as 5.6 N in force and 1.2 mm in depth and as much as 123 N and 16.9 mm, respectively, when repeatedly performed by the same practitioner. This represents as much as a 50% difference in the force or depth applied in any instance of performing the toggle-recoil SMT procedure. Inconsistent performance within and between practitioners has also been noted for other forms of SMT (Ngan et al., 2005). There is some evidence, for example, that at least one form of mobilization (cervical lateral glide) has very small intra-practitioner variability (Vicenzino et al., 1999).

In conclusion, this study has demonstrated that considerable variability exists in the force and displacement generated by practitioners using the toggle recoil high velocity SMT procedure. Furthermore, this variability is apparent when an individual practitioner performs the procedure over multiple occasions.

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